PREVIEW: Inside the new ***Cosmos*** TV series p. 12

APRIL 2014

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Finding the missing universe

Does dark matter define the cosmos? p. 24

Solving the mystery of cosmic rays p. 30

The next search for Earth-like worlds p. 44

Observe this month's spectacular **LUNAR ECLIPSE** p. 52

Astronomy tests Meade's new 10-inch SCT p. 62

The intricate beauty expressed in NGC 772, an interacting pair of galaxies, could not happen without mysterious dark matter — unless scientists don't understand gravity.

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FROM THE **EDITOR**

BY DAVID J. EICHER

Cosmic Origins arrives!

Imagine bringing a print issue of your favorite astronomy magazine to life — with interactive, complex graphics, embedded video, images that move, and explanations that show you how the universe works with motion and meaning. That day has arrived.

For the past several months, *Astronomy*'s staff has been working on a new type of product. Under the watch of Associate Editor Liz Kruesi, we have produced our first all-digital astronomy app — a book, a magazine, an interactive educational toy, a beautifully illustrated tour of the cosmos, and much more, all in one. Titled *Cosmic Origins*, the work consists of four pieces, *How the universe began*, *How galaxies came to be*, *How stars form and evolve*, and *How the solar system formed*.

The *Cosmic Origins* package is a first in the astronomy world and is available via the Apple App Store and the Google Play store.

You can interact with many of the graphics, watch videos, view galleries of images, and more. *Astronomy*'s editors and a great art and design team have worked with top astronomers and science journalists to create these article packages to help you understand the origin and evolution of everything the universe contains.

In *How the universe began*, you will learn about the Big Bang, how the first elements formed, and how the cosmos could end.

If you want to discover how black holes affect the universe and how galaxies and their larger conglomerates — galaxy clusters — form and evolve through time, check out *How galaxies came to be*.

In *How stars form and evolve*, you'll learn about the first stars, how stars form, how they create elements, how black holes form, and how scientists have deduced where the Sun was born.

How the solar system formed describes Earth's fiery beginning, the huge collision that likely created the Moon, how exoplanets are casting light on planet formation, and ideas about how life started on our planet. The recent explosion of exoplanet discoveries has shed light not only on planets around us in the galaxy, but also on our home solar system.

We're excited about these new and unique digital interactive products. Let us know how you are enjoying them, and we will enter a new era of exploring the universe together!

Yours truly,

David J. Eicher
Editor

Astronomy

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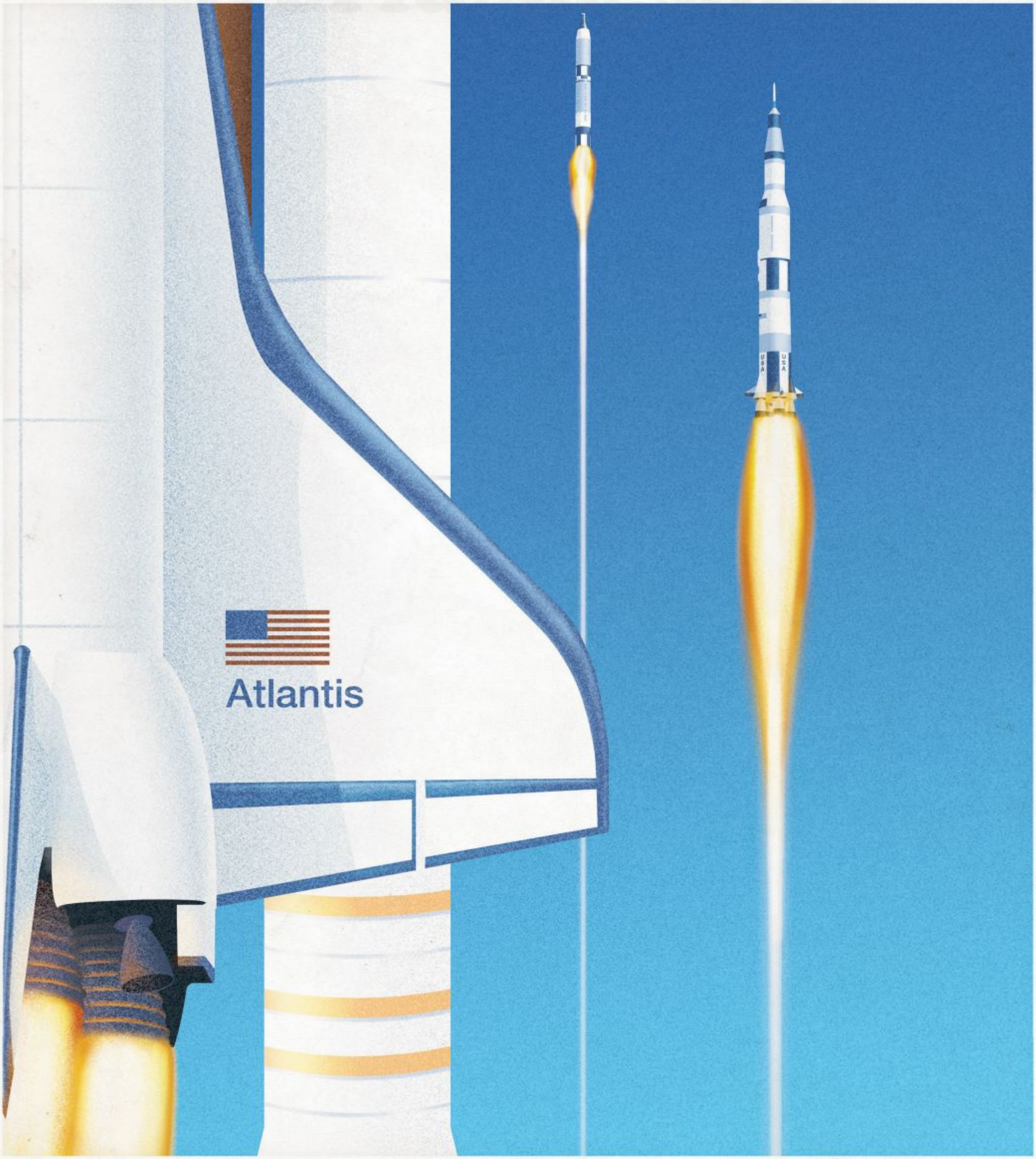
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QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES>>

TRENDING TO THE TOP

HIDDEN DETAILS
New radio observations of galaxy M82 uncovered dense gas around star formation regions and streams of ionized gas leaving the galaxy.

PLANET PHOTO
Researchers released this image January 7 of Beta Pictoris b from the new Gemini Planet Imager attached to the Gemini South Telescope in Chile.

SATURN SHAPE
Scientists with NASA's Cassini mission released a high-resolution video of the six-sided jet stream (the hexagon) at Saturn's north pole December 4.

SNAPSHOT

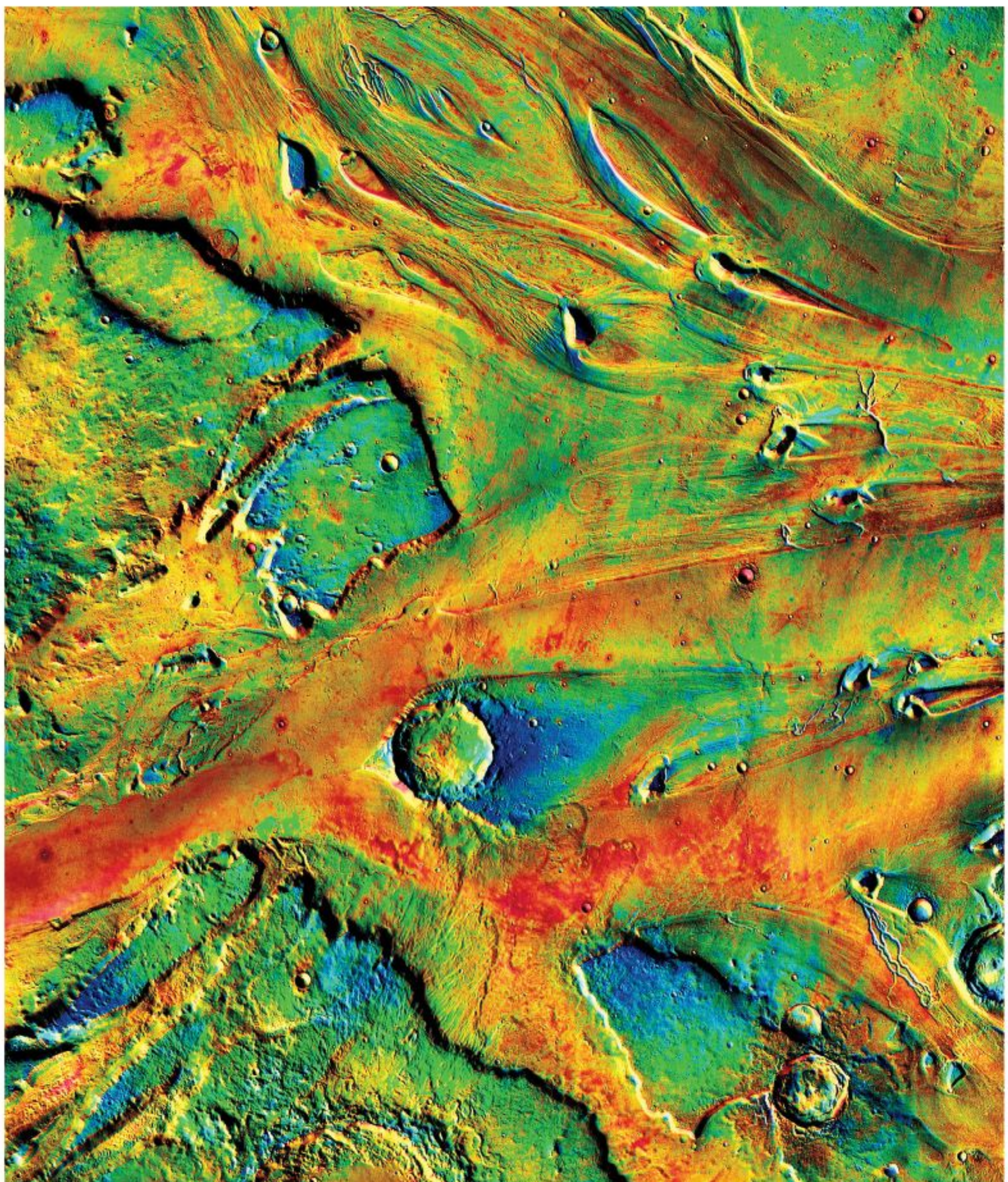
Why did Mars go cold and dry?

Water is a common thread between Mars and Earth.

The majority of NASA's planetary science budget over the past generation has focused on Mars. And for good reason: The terrestrial planet most similar to Earth, Mars shows evidence of a watery past, and where there's water, there also might be life. Despite abundant evidence of a warm, wet Mars in the distant past, the first billion or so years of the planet's existence, the Red Planet is now cold and dry — a desert. So where did all the water go?

Evidence of water exists in many places, including in the sulfate rocks examined by several martian rovers and in evidence for ice in various places around the planet (and below its surface). Water-eroded valleys, gullies, branching valley networks, layered deposits (possibly from once-existing lakes), and outflow channels extending from the ends of canyons all provide more reasons scientists believe that water/liquid flowed on the martian surface.

The reason why Mars was warm and wet early on, and why it transformed some 3 billion or more years ago, remains elusive. But the answers may hold important lessons for our own planet. — **David J. Eicher**

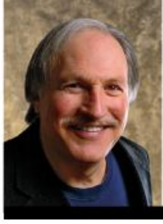


In Mars' distant past, gushing floodwaters formed channels in Kasei Valles, shown here in false color from the Mars Reconnaissance Orbiter spacecraft. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA/HiRISE

BILL SAXTON (NRAO/AUI/NSF)/HUBBLE/NASA (HIDDEN DETAILS); PROCESSING BY CHRISTIAN MAROIS, NRC CANADA (PLANET IMAGER); NASA/JPL-CALTECH/SSI/HAMPTON UNIVERSITY (SATURN SHAPE)

Echoes of an aging star

A thick blanket of dust and gas wraps around the Cepheid variable star RS Puppis. This 13-solar-mass star has consumed most of the hydrogen fuel in its core and no longer shines steadily. Instead, it pulsates rhythmically with a period of 41.4 days, during which its light output varies by a factor of nearly five. At maximum brightness, the Cepheid radiates as much light as 15,000 Suns. As RS Pup waxes and wanes, the changing light levels reflect off its dusty sheath. Astronomers used this "light echo" effect to measure the star's distance geometrically, pinpointing it at 6,500 light-years away from Earth. NASA/ESA/HUBBLE HERITAGE TEAM (STScI/AURA)-HUBBLE/EUROPE COLLABORATION



STRANGE**UNIVERSE**

BY BOB BERMAN

The Belt of Orion

Explore the lore, science, and observing challenges of this stellar trio.

What's your first star memory? You probably observed the three luminaries of Orion's Belt before anything else. Most kids notice it even before the Big Dipper or, in places Down Under, the Southern Cross. There's nothing else like it in the heavens. Moreover, unlike other eye-catching constellations, Orion lies on the celestial equator. It alone stands visible throughout the world.

Because the Belt stars are fairly bright at 2nd magnitude, matching Polaris and six of the seven Big Dipper stars, Orion successfully withstands most light pollution. It isn't visible from Beijing but does appear over New York's Times Square.

To the ancient Sumerians, Orion was a sheep. But most cultures visualized a human. Not necessarily a hunter, of course; the starry shape would just as easily fit a vegetarian or a dental hygienist. Still, widely separated civilizations like the Greeks and the natives of Mexico called it a hunter. The Chinese, as usual, went their own way. They always broke stars into small groupings and regarded the Belt as unrelated to the rest of the constellation.

In March and early April from the Northern Hemisphere, Orion stands high at nightfall. (From below the equator, it appears upside down, as if the Hunter has inexplicably taken up yoga.) When you next observe it this spring, consider the spacing of the Belt stars. The middle one, Alnilam (al-NY-lam), appears perfectly centered between Mintaka (MIHN-tah-kah) on the right and Alnitak (al-NY-tak) on the left. Couldn't be better. As for its geometrical straightness, only type-A Virgo nitpickers would complain that Alnilam sits ever so slightly below an imaginary chalk line snapped between the extremity stars. In Arabic, all three, well matched in brightness, translate to "belt" or "girdle." It's the sky's only article of clothing. No one's ever said, "Oh look, there's Andromeda's underpants," or, "Perseus' sneakers look pretty ratty."

Astrometric measurements from the Hipparcos satellite show that Alnilam, at a hefty 1,340 light-years away, lies significantly farther than the other two. It must therefore be much more intrinsically brilliant. Turns out, it shines with the same light as 375,000 Suns. Of all the night's stars with proper names, it's the most luminous.

THE MIDDLE ONE, ALNILAM, APPEARS PERFECTLY CENTERED BETWEEN MINTAKA ON THE RIGHT AND ALNITAK ON THE LEFT.

Placed so unmistakably in the center of Orion's Belt, Alnilam is one of the 57 stars used in navigation. If only all the rest of that Heinz variety were so easy to locate, the back-to-nature crowd might be tempted to toss their GPS units.

While the entire Belt hovers within 2° of the zenith for observers at the equator, Mintaka has a 0° declination. It is the nearest bright star to the celestial equator, missing it by a negligible 0.3°. When viewed on a long-exposure photo, other stars make circles or arcs as they travel; Mintaka crosses the sky in a straight line. This luminous mile marker reveals the dividing line between the Northern and Southern Hemispheres.

The final Belt member, Alnitak, enjoys its own superlative too. It is the sky's brightest O-class star, that rare ultra-hot category. These stars are automatically young — because they die relatively quickly. Alnitak conjures that line from *Blade Runner*: "The light that burns twice as bright burns half as long — and you have burned so very, very brightly …"

If you follow the Belt down and left this spring, it takes you to blue Sirius, the Dog Star. The brightest nighttime star, it's surpassed this winter by creamy Jupiter, much higher, which shines six times more brightly. If you follow the Belt the opposite way, up and right, it takes you to a vertical line of faint stars that make up Orion's … well, what is it, exactly?

Unimaginatively named Pi^1 (π^1), Pi^2, Pi^3, Pi^4, and then, after a gap, Pi^5 and Pi^6, this star stream looks like a large shield Orion wields as he does battle. We probably all see it that way. Except he's not a warrior but a hunter, and what huntsman carries a shield? Maybe he's stalking porcupines.

Through binoculars, the bright Belt stars are embedded in a wonderful diffuse star cluster that only goes by the designation Collinder 70. From excellent skies and with just the naked eye, this group appears as a strange glow surrounding the Belt. When eyes become dark-adapted, individual members of this wondrous cluster flicker in and out of sight. I regard the ability to see these little cluster stars as a stringent test of an observing site's purity, although many people don't even know it exists. Its relative anonymity is odd indeed. You'd think its easy location and richness would merit equal status with the Beehive and other famous clusters.

On every level — lore, mythology, science, observing challenges — the Belt of Orion lives up to the intrigue it visited upon us as kids, on those cold nights long ago.

Contact me about my strange universe by visiting **http://skymanbob.com.**

QG

COSMIC WORLD

A look at the best and the worst that astronomy and space science have to offer. **by Sarah Scoles**

Cold as space — Supernova hot

Scary science

The University of Missouri turns its observatory into a haunted house. Kids ask "dead" scientists why they were famous. Only one replies, "Scaring smart children away from astronomy."

Asteromet?

NASA reports that scientists were "literally dumbfounded" by an asteroid with six comet-like tails. Others contend the scientists were merely figuratively dumbfounded.

Science guy

An Arizona professor invites Bill Nye to teach for a day. All of the students' questions, though, are not about astronomy but about Nye's lackluster *Dancing with the Stars* performances.

Reckless driving

Video game *Gran Turismo 6* has a lunar vehicle race and a sidereally rotating sky. The game will inspire kids to become astronomers, run people over, and take corners too fast.

CENTRAL MISSOURI ASTRONOMICAL ASSOCIATION (SCARY SCIENCE); NASA/ESA/D. JEWITT (UCLA)/J. AGARWAL (MAX PLANCK INSTITUTE FOR SOLAR SYSTEM RESEARCH)/H. WEAVER (JHUAPL)/M. MUTCHLER (STScI)/S. LARSON (UNIV. OF ARIZONA) (ASTEROMET?); ED SCHIPUL (SCIENCE GUY); NASA (RECKLESS DRIVING)

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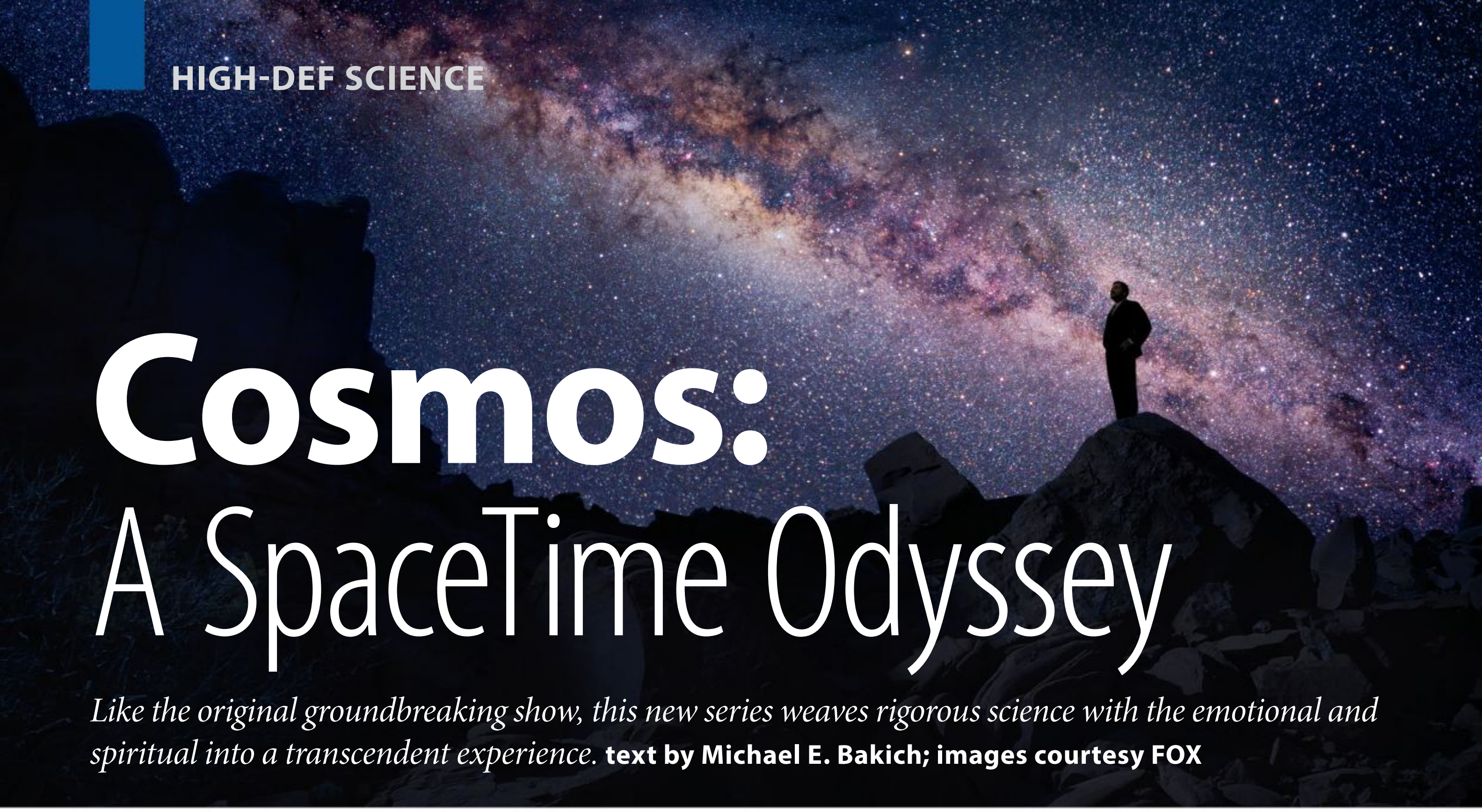


Cosmos: A SpaceTime Odyssey

Like the original groundbreaking show, this new series weaves rigorous science with the emotional and spiritual into a transcendent experience. **text by Michael E. Bakich; images courtesy FOX**

COSMOS. When uncapitalized and preceded by "the," this word conjures up a possibly limitless universe filled with planets, galaxy clusters, and dark energy. But frame it as a single word, and it takes on a different, albeit related, meaning. For those of a certain age, it likely triggers memories of the greatest science television event of the 20th century. And although that 13-part epic carried the title *Cosmos: A Personal Voyage*, everyone who saw it — even 34 years later — refers to it as simply *Cosmos*. And each of those viewers, a total that now reaches a staggering 750 million scattered throughout 60 countries, remembers the inimitable host, Carl Sagan.

If you didn't see it, you missed something truly historic. But excitement is building that the follow-up series, *Cosmos: A SpaceTime Odyssey*, could be just as special. It debuts Sunday night, March 9, at 9 P.M. EDT/PDT on FOX.

The next night, March 10, the National Geographic Channel will run the episode with bonus footage and behind-the-scenes content. And that's just the beginning.

In addition to the North American showings listed above, *Cosmos* will begin premiering globally March 10 in 170 countries and 45 languages.

Someone truly special

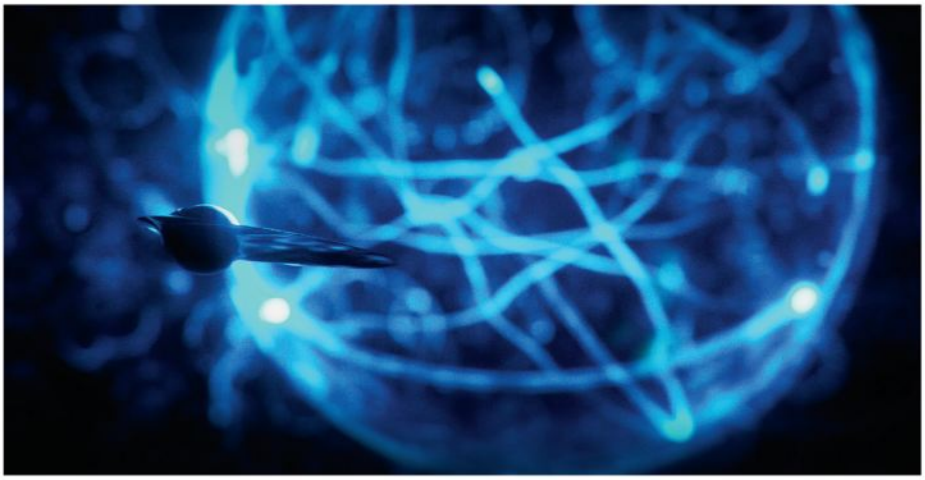
Sagan, who passed away December 20, 1996, was the face most people associated with astronomy for more than two decades — especially after *Cosmos* debuted.

Luckily, a friend of the family has stepped in: author, science communicator, and director of the Hayden Planetarium in New York, Neil deGrasse Tyson. Tyson met Sagan when he was still in high school. The student had applied to Cornell University, and Sagan, who had seen Tyson's application, invited him there for a tour. Tyson accepted but chose to attend Harvard instead. Still, he often speaks of the inspiration Sagan was to him. He became a noted astrophysicist in his own right and stayed in touch with the family.

And on March 9, Tyson will become the new face of *Cosmos* to audiences around the world. He will travel throughout the universe, large and small, guiding viewers in an updated version of a creation from the first series — the *Ship of the Imagination*.

Something truly special

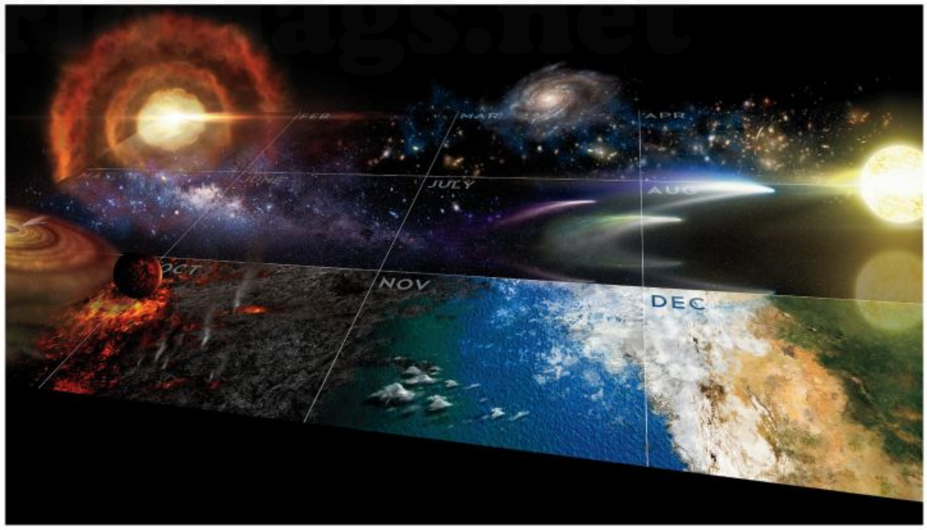
Ann Druyan, Sagan's widow and one of the writers of both *Cosmos* series, offered the following observation about her



Cosmos: A SpaceTime Odyssey **will explore inner as well as outer space. Here, the *Ship of the Imagination* is about to enter the nucleus of a hydrogen atom.**

Michael E. Bakich *is a senior editor of* Astronomy *who remembers watching* Cosmos: A Personal Voyage *numerous times.*

Astrophysicist Neil deGrasse Tyson hosts ***Cosmos: A SpaceTime Odyssey*. He met Carl Sagan while still a high school student. They remained friends throughout Sagan's life.**



The "Cosmic Calendar" is a graphic way to envision the universe's 13.8-billion-year history in a single year. The original *Cosmos* popularized it, and the new series will feature an updated version.

In this image, the *Ship of the Imagination* descends into the turgid depths of Kraken Mare, the largest known body of liquid (methane and ethane) on Saturn's giant moon Titan.

involvement: "This one was similar because of the morale of our whole team," she says, "in the sense of wanting to do something that would truly be special." Druyan also notes that the team wanted the final product to be worthy of the original. "Memory is subjective," she said, "but I can say that they have been two wonderful experiences."

For the new series, she wrote the final drafts for all 13 episodes. She'd co-written the original with Sagan and astrophysicist Steven Soter, who also helped pen the new series. Other executive producers of the new series include actor and director Seth MacFarlane, producer Mitchell Cannold, and screenwriter Brannon Braga. Braga directs the new series with cinematographer and director Bill Pope.

A lot has changed

The new *Cosmos* will have an enormous amount of fresh ground to cover if you consider recent astronomical history. When the original series debuted September 28, 1980, planetary exploration was in its infancy. That month's issue of *Astronomy* highlighted the large moons of Jupiter in the story "Four new worlds." The spacecraft Voyager 1 and Voyager 2 had visited the planet in 1979 and were headed to Saturn.

That month's imaging story was "A darkroom for astrophotography" — *film* photography. No amateurs were using CCD cameras yet. The magazine's first story about them appeared two months later.

Oh, and exoplanets? We didn't know of any. The first definitive detection was still nearly 12 years away. Confirmed discoveries now number more than 1,000.

Cosmos: A SpaceTime Odyssey will be an up-to-date account of science today. But will it convey the same deep feeling as the original? Yes, according to Druyan. "*Cosmos* lies at that intersection of wide-eyed wonder and rigorous skepticism," she says. "For me, I don't want the things I feel to be at the expense of the things I know. And the things that I know, I don't want them to diminish what I feel. If the stories didn't walk the line between knowing and feeling, it just wouldn't be *Cosmos*."

What would Carl think?

Druyan asks herself this question every day. She takes great comfort in hearing from family and the people who knew Sagan best that he would be proud of the new series. "In my heart of hearts, I know Carl would understand how hard I struggled to make it as good as I possibly could," she says.

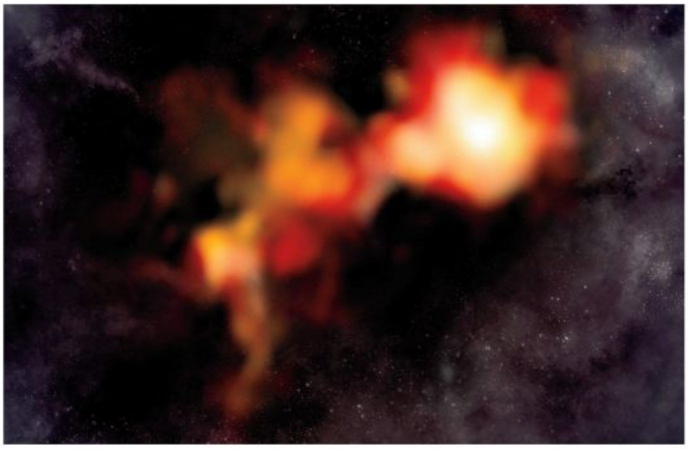
Druyan wishes she could have taken this journey with Sagan. In the absence of that, however, she thinks he would salute the new show with a gesture he made when he wanted to compliment her professionally. "He would look at me and doff an imaginary hat in my direction," she says, "and it gave me great happiness. In my mind, I hope that's what Carl is doing."

And on March 9, it's likely that TV viewers around the world will be tipping their collective hat toward Druyan and the entire *Cosmos* team.

FIND OUT ABOUT THE *ASTRONOMY* STAFF'S UPCOMING EPISODE RECAPS AT **www.Astronomy.com/toc.**

ASTRO**NEWS**

DOUBLE DISK. Astronomers reported online December 17 in the *Monthly Notices of the Royal Astronomical Society Letters* that the brightest and faintest stars in the triple system Fomalhaut have their own comet belts.



BILL SAXTON/ALEXANDRA ANGELICH/NRAO/AUI/NSF/ALMA/ESO/NAOJ

ALMOST STARS. The Atacama Large Millimeter/submillimeter Array imaged two "starless cores," dense pockets of gas nearly ready to form stars. The rightmost core is bright, rounded, and likely will collapse into a single massive star, while the one on the left may fragment into smaller, more common stars.

MASSIVE AND MEDIUM STARS GROW THE SAME WAY

Stars vary from tiny and red to gigantic and blue. While small stars are abundant in the Milky Way, massive ones — at least eight times the Sun's mass — are rare. Scientists have long wondered how huge stars grow to such proportions. An article in the December 20 issue of *The Astrophysical Journal* proposes that magnetic fields inside certain star-forming regions stall the gas clouds' collapse, allowing stellar embryos to gestate for longer periods before they move on to their next phase of development.

Stars like the Sun form in the cores of molecular clouds. Parts of the cores collapse under their own gravity, forming kernels that then attract more gas. Eventually, the kernels grow massive and hot enough to begin fusion. But if massive stars also form this way, why don't the clouds always collapse at similar points, forming kernels — and thus future stars — of similar sizes?

A research team led by Jonathan Tan of the University of Florida in Gainesville set out looking for "starless cores" — dense regions of gas through which no starlight yet shines. "A starless core would indicate that some force was balancing out the pull of gravity, regulating star formation, and allowing vast amounts of material to accumulate in a scaled-up version of the way our own Sun formed," says Tan.

Tan's team found what they were looking for, using the Atacama Large Millimeter/submillimeter Array (ALMA) to take the temperatures of massive molecular clouds and determine whether young stars had heated the gas. They had not, which means an outward-pressing force is keeping the cores from collapsing and giving the gas kernels time to grow larger. The astronomers think magnetic field lines may prop the cloud up, balancing the gravitational urge, at least for a while. **— Sarah Scoles**

Astronomers map 1,500 clouds — in another galaxy

SEA CHANGE. Astronomers have created a *National Geographic*-worthy "cloud atlas" that shows where clouds of molecular gas are in the Whirlpool Galaxy (M51). Where gravity causes these clumps to collapse and contract, stars form from the gas. Scientists thought these clouds were autonomous, giving birth to stars because of their own internal dynamics. However, the detailed map of M51's molecules shows that while each cloud is an island, they are all embedded in a lower-density sea of molecular gas. This external ocean envelops the clouds, exerting pressure on them from the outside and spurring their collapse. Here, the blue shows the distribution of hydrogen molecules, including more than 1,500 clouds; the background is a Hubble Space Telescope image; and the red shows the location of atomic hydrogen. The results appeared in the December 10 issue of *The Astrophysical Journal*. **— S. S.**

PAWS TEAM/IRAM/NASA HST/T. A. RECTOR (UNIVERSITY OF ALASKA ANCHORAGE)

BRIEFCASE

FAST FLARES

In 2007, astronomers saw ultra-fast bursts of radio waves coming from … something. In 2013, they determined that these millisecond outbursts came from energetic (but unknown) sources outside the Milky Way. In a forthcoming issue of the *Monthly Notices of the Royal Astronomical Society*, however, other researchers propose that the bursts' origins are nearby and mundane: flares from young binary stars. **— S. S.**

BIPEDAL SATELLITE

By May 2013, the Kepler satellite had lost control of two of the four reaction wheels that keep its eye precisely pointed. Without its full faculties, the spacecraft was unable to continue its search for exoplanets. On December 4, however, scientists proposed pointing Kepler only along the plane of Earth's orbit. If the proposal is approved, pressure from the Sun's photons would prop the satellite up, rendering it stable enough that the remaining two wheels could balance it. **— S. S.**

MILKY WAY'S STRUCTURE

Astronomers study the distribution of massive stars in the Milky Way to deduce our galaxy's shape. Such suns have short life spans — a few million years — and reside only in the Milky Way's spiral arms. After a 12-year study of about 1,650 stars with radio telescopes across the globe, researchers conclude in the January 11 issue of the *Monthly Notices of the Royal Astronomical Society* that our galaxy has four major spiral arms, not two major and two minor as others have suggested. **— Liz Kruesi**

Europa spews water

Decades of observations of Europa suggest that the jovian moon harbors a thick subsurface ocean below a layer of ice. Scientists now have evidence that plumes of water also erupt from its surface. The new study appeared in the January 18 *Science*.

NASA/ESA/L. ROTH (SwRI & UNIV. OF COLOGNE, GERMANY)

WATER SPOUT. Scientists found evidence of water erupting at Europa's south pole, represented in blue. The water illustration is based off the location of detected hydrogen and oxygen.

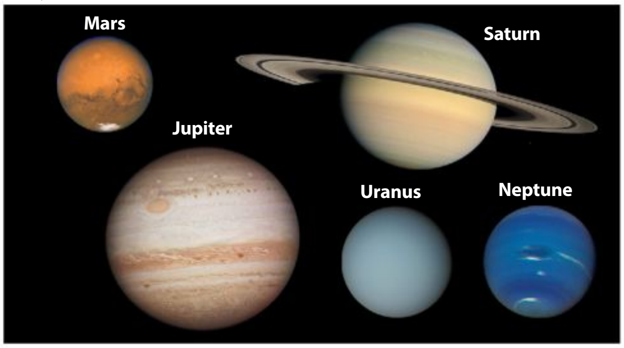
The team, led by Lorenz Roth of the Southwest Research Institute in San Antonio, Texas, used the ultraviolet instrument on the Hubble Space Telescope to study Europa for seven hours in November and December 2012. The researchers subtracted out the Sun's reflected light and were left with radiation of wavelengths specifically corresponding to oxygen and hydrogen near the moon's south pole. Roth's team thinks that as electrons slam into water and molecular oxygen in Europa's atmosphere, they break the molecules apart to create the oxygen and hydrogen signatures.

The vapor signal was strongest when the moon was near its farthest point from Jupiter in its orbit, which occurred in December. The planet's gravity stretches and squeezes Europa, and at this apocenter point, the moon takes on more of a pancake shape than spherical shape, with the polar regions slightly flattened. These tidal stresses could cause cracks in the ice to open wider while Europa is at its farthest point. The scientists don't have evidence that the water vapor detected at the moon's south polar region came from an ocean. **— L. K.**

FAST FACT

According to NASA, the solar system's eight major planets hold 146 permanent natural moons and 27 temporary ones.

QUIZ WHAT PLANET DOES EACH NATURAL SATELLITE BELONG TO?



ANSWERS: MARS (DEIMOS); JUPITER (GANYMEDE, THEBE); SATURN (JANUS, PANDORA); URANUS (MIRANDA, TITANIA); NEPTUNE (TRITON)

NASA/J. BELL (CORNELL UNIV.)/M. WOLFF (SSI) (MARS); NASA/DAMIAN PEACH (JUPITER); NASA/JPL/SSI (JANUS, PANDORA, SATURN); NASA/JPL (GANYMEDE, MIRANDA, NEPTUNE, TITANIA, TRITON, URANUS); NASA/JPL/CORNELL UNIV. (THEBE); NASA/JPL-CALTECH/ UNIV. OF ARIZONA (DEIMOS)

151,524 The number of X-ray point sources detected by the X-ray telescope on NASA's Swift satellite, according to the January issue of *The Astrophysical Journal Supplement Series*.

QUICK TAKES

STELLAR DEATH

A study in the December 20 issue of *The Astrophysical Journal* suggests that the formation of a dense stellar remnant called a magnetar powers a superluminous supernova.

PHOSPHORUS FOUND

Researchers report in the December 13 issue of *Science* their discovery of phosphorus, an element essential for life, in the supernova remnant Cassiopeia A.

NOBLE GAS

The Crab Nebula (M1) hosts argon-containing molecules, compounds not expected in space, report astronomers in the December 13 *Science*.

FUTURE SCOPE

Construction of a road to the summit of Cerro Armazones in Chile's Atacama Desert — the future site of the 39-meter European Extremely Large Telescope — began in March.

STELLAR SPIES

Scientists used submillimeter telescopes to peer through the dust and study W49, the Milky Way's most luminous star formation region. The findings appeared in the December 20 issue of *The Astrophysical Journal*.

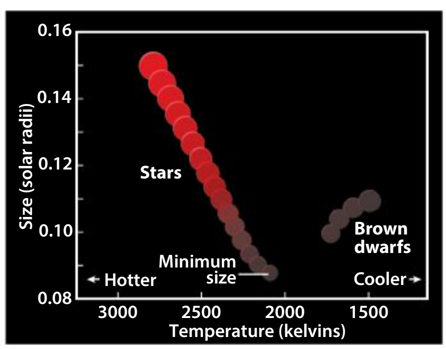
LACKING GRIT?

Astronomers say in a January 9 *Nature* study that the star-forming galaxy Himiko, which existed in the universe's first billion years, has less dust than expected. — **L. K.**

Defining the boundary between stars and brown dwarfs

Brown dwarfs are often referred to as "failed stars" because they're more massive than planets but too small to ignite and sustain hydrogen fusion in their cores — the main characteristic of any star. But since discovering this type of object in 1995, scientists have been unable to determine exactly what is this size dividing line between stars and brown dwarfs. By studying 63 objects that are near this boundary, astronomers with the Research Consortium On Nearby Stars (RECONS) have found clear observational evidence that indicate key parameters separating the two types of objects.

To determine these parameters, the RECONS group looked for an important difference between the internal processes of normal, or "main sequence," stars and brown dwarfs. While normal stars increase in diameter as they increase in mass (and therefore temperature), brown dwarfs do the opposite. Based on the 63 objects the astronomers observed, they saw an expected stellar size-temperature relationship to a certain temperature, a gap, and then an expected brown dwarf size-temperature relationship below that temperature gap. "We can now point to a temperature (2100 kelvins [3300° Fahrenheit]), radius (8.7 percent that of our Sun), and luminosity (1/8,000 of the Sun) and say, 'The main sequence ends there,'" says co-author Todd Henry of Georgia State University in Atlanta. The team's results will appear in a future issue of *The Astronomical Journal*. — **Karri Ferron**



BROWN DWARF BOUNDARY. Astronomers have determined that the temperature boundary between normal stars and "failed stars," also known as brown dwarfs, is about 2100 kelvins. P. MARENFELD & NOAO/AURA/NSF

OBSERVING**BASICS**
BY GLENN CHAPLE

Eclipse escapades

Get the most from the first total lunar eclipse since 2011.

Psst! Wanna know the real reason why the Boston Red Sox won the 2004 World Series — their first after 86 years of futility? Certainly, pitchers Curt Schilling and Pedro Martínez and sluggers Manny Ramírez and David Ortiz contributed, but it was a total lunar eclipse coinciding with the Series clincher October 27 that sealed the deal.

How else can you explain the end of a jinx that began with the infamous sale of Red Sox star pitcher/outfielder Babe Ruth to the New York Yankees late in 1919 and continued through season after season of inexplicable near misses and what ifs? Even a spell cast by a self-proclaimed Salem witch prior to the 1975 World Series failed to help the Sox. It took nothing less than a cosmic intervention to finally "reverse the curse" in 2004.

As a Red Sox fan, it's easy to be superstitious about a lunar eclipse; as an amateur astronomer, I know better. After all, a lunar eclipse is nothing more than the passage of the Moon, when at Full phase, through Earth's shadow. In the years following the "eclipse championship of 2004," the Red Sox have added two more World Series titles with nary an assist from an eclipse, comet, or unusual planetary alignment (well, maybe a tiny boost from Comet ISON [C/2012 S1] last fall).

Last month, I described a celestial happening (the March 20 occultation of Regulus by the minor planet Epigone) that was visible to a tiny fraction of Earth's populace situated on a 67-mile-wide (108 kilometers) strip between the mid-North Atlantic and the Arctic. A total lunar eclipse is much more accessible, being visible from the entire side of Earth facing the Moon at the time. The one that occurs April 15 (or the 14th for those on the West Coast) will entertain skygazers throughout most of the Americas and much of the Pacific region. You'll find specific details on p. 52 of this issue.

The Moon often takes on an orange-red hue during a total lunar eclipse. What color will our satellite appear April 15? CHRISTOPHER GO

The entire eclipse runs from 12:53 to 6:38 A.M. EDT — the wee hours of a Tuesday morning for many residents of the eastern U.S. and Canada and all of South America. You can sleep a little longer by forgoing the beginning penumbral stage and waiting for the onset of the umbral phase at 1:58 A.M. EDT, when the Moon encounters the truly dark part of Earth's shadow. Want more sleep? After totality, which runs from 3:06 to 4:25 A.M. EDT, the remainder of the eclipse is a reverse of the earlier stages. You can get your fill of totality and then return indoors to a warm, comfy bed (my tactic for this eclipse).

The partial stages of lunar eclipses may be similar, but we never know what to expect during totality. That's because the eclipsed Moon is aglow with sunlight refracted through Earth's atmosphere, and its condition can be dramatically different from one eclipse to another. The Moon usually takes on an unnatural coppery red hue, but there are exceptions.

The most amazing lunar eclipse I have ever witnessed was one that occurred during the morning hours of December 30, 1982, several months after an eruption of Mexico's El Chichón volcano blasted huge quantities of sulfur dioxide and particulates into the atmosphere. During mid-eclipse, the Moon was barely visible to the unaided eye. I could scarcely make out its ghostly form, even when viewing through a 13.1-inch reflector!

As you gaze at the fully eclipsed Moon, imagine for a moment what it might be like to stand on its surface, gazing earthward. You'd be witnessing the spectacle of a total solar eclipse, with Earth serving as the eclipsing body. Our planet's dark disk, four times wider than the Moon's, would be encircled by a thin, but brilliant red halo (sunlight refracted by Earth's atmosphere) that would bathe the lunar surface with an eerie ruddy glow.

If you live in a region untouched by this month's eclipse or if clouds spoil the event, fear not. A repeat performance October 8 will be observable throughout much of the Pacific area. You can also find a list of the remaining total lunar eclipses for the current decade on this page, courtesy of NASA and Fred Espenak (http://eclipse.gsfc.nasa.gov/lunar.html).

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: An astronomical salute to Cinco de Mayo. Clear skies!

FROM OUR INBOX

Quantity versus quality

"Speaking the language of the cosmos" in the December 2013 issue is the kind of article many of us have wanted to see. I'm sure it helped those like me who have had a little math training but will never be able to understand the deep complexities of some current astronomical research. These things are not explainable except by higher math and blackboards full of equations that are hopelessly beyond most of us. I think there are a lot of people who would like to see more articles that explain the various aspects of astronomy in a quantitative way. — **Henry Jorgensen,** Ajo, Arizona

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

UPCOMING TOTAL LUNAR ECLIPSES

DATE	REGION OF VISIBILITY
Oct. 8, 2014	Asia, Australia, Pacific, Americas
April 4, 2015	Asia, Australia, Pacific, Americas
Sept. 28, 2015	E. Pacific, Americas, Europe, Africa, W. Asia
Jan. 31, 2018	Asia, Australia, Pacific, W. N. America
July 27, 2018	S. America, Europe, Africa, Asia, Australia
Jan. 21, 2019	C. Pacific, Americas, Europe, Africa

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

TO THE MOON. The Chang'e-3 mission, China's first lunar rover, successfully landed on the Moon on December 14.

SPACE SCIENCE UPDATE

GAIA LAUNCHES TO CATALOG AND MAP THE STARS

ESA/ATG MEDIALAB (GAIA); ESO/S. BRUNIER (MILKY WAY PHOTOGRAPH)

STAR SEARCHER. The European Space Agency's Gaia mission, shown in this illustration, launched in December and will map a billion stars.

A new space observatory will help astronomers piece together stellar life cycles and learn how our galaxy evolved. The Gaia mission launched December 19, 2013, to collect data about all stars brighter than magnitude 20, which translates to roughly 1 billion stars in the Milky Way. It will record the distance, brightness, color, and movement of each of those suns. Astronomers will then compile that data into a 3-D map of the galaxy.

This European Space Agency satellite will view the whole sky and collect about 70 sets of observations of those 1 billion stars over its five-year mission. By comparing the observations, astronomers can measure not only the stars' stable characteristics but also how they change — thus, how they move and how their brightness fluctuates. Gaia also will gather data that will allow astronomers to determine the composition of those stars brighter than magnitude 17.

Gaia researchers expect to discover thousands of planets around other suns by observing the slight position changes of a star due to the gravity of an orbiting planet. They also anticipate finding thousands of exploding stars called supernovae outside the Milky Way and being able to determine which original stars corresponded to those that ended their lives. "In addition, Gaia will observe somewhere between 1 and 10 million galaxies, about half a million quasars, and some 300,000 solar system bodies (asteroids)," says team member Anthony G. A. Brown of Leiden University in the Netherlands.

Gaia has two identical telescopes with primary mirrors measuring 1.45 meters by 0.5 meter. The collected light is then funneled into three instruments: an astrometric instrument, a photometer, and a spectrometer. "Gaia's mirrors are comparable in size to those of the Hubble Space Telescope," says Brown, "meaning that Gaia will produce an all-sky star map to 20th magnitude at a resolution similar to that of HST."

The observatory will begin taking data in May, and team members expect the first data release and sky map in late 2015 or early 2016. **— L. K.**

NASA IS EVERYWHERE

FAST FACT

Goddard Space Flight Center employs the most people — 19 percent of NASA's total.

MANIFEST DESTINY. NASA has 11 different centers across the United States. Each is in charge of some combination of development, construction, data analysis, and business for the agency. NASA employs nearly 80,000 people and supports 161 active missions on its $17.7 billion budget. *ASTRONOMY:* SARAH SCOLES AND ROEN KELLY, AFTER NASA

Telescopes must observe gamma-ray bursts quickly because information about the physics of the fundamental fireball and its magnetic field are encoded in the event's light for only a few minutes.

FAST FACT

WHAT HAVE WE DISCOVERED ABOUT THE PHYSICS OF GAMMA-RAY BURSTS?

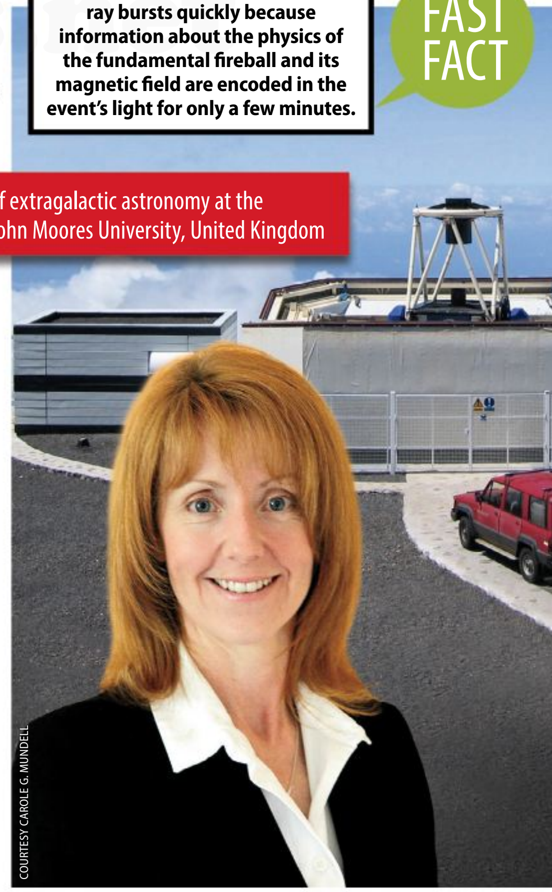
Carole G. **Mundell** Professor of extragalactic astronomy at the Liverpool John Moores University, United Kingdom

Gamma-ray bursts (GRBs) come from some of the most energetic explosions in the universe. Because they are so bright and distant, we know that they can't produce their light isotropically — the same in all directions. Their light must instead be focused into a beam or jet, and when that jet points toward Earth, we see this very bright blast from the GRB.

But what powers these events? For GRBs, the magnetic field question is really the big unsolved problem: What is the role of the magnetic field in these events? Some models said that the magnetic field must power the whole thing, while others said that it is not important at all.

My GRB team uses the robotic Liverpool Telescope to capture the optical light from GRBs within the first few minutes after a gamma-ray satellite has discovered a burst. Although much useful information is encoded in the fading light, we realized that measuring the fading rate alone was not enough to probe the magnetic field because competing models predict the same fading behavior. Fortunately, the models were drastically different in their predictions of polarization — whether the light has a preferred angle; high polarization means ordered magnetic fields. The sooner the polarization is measured, the better the chance of probing the field before it is destroyed as the expanding jet crashes into the surrounding medium.

So we built the RINGO2 polarimeter instrument for the Liverpool Telescope, which autonomously made measurements minutes after the discovery of a GRB on March 8, 2012. Not only did the analyzed data show a high polarization degree — the highest ever measured — but its position angle stayed remarkably constant throughout, telling us that large-scale, ordered magnetic fields were present in the jet and had survived long after the initial explosion. This was direct proof that the magnetic fields originate from the central engine. As the magnetic field is able to stay well-structured, it may therefore help to accelerate the jet to high speeds.



COURTESY CAROLE G. MUNDELL

SECRET SKY

BY STEPHEN JAMES O'MEARA

Moonlight and Paul Revere

The Moon's phases aren't just for decoration. The Sons of Liberty took advantage of lunar light and shadow.

THINKSTOCK/JORGE SALCEDO/ISTOCK

Paul Revere, seen here in statue form, made his famous ride from Boston's North End to Lexington in 1775. His success in warning his friends about their intended capture by British soldiers soldiers may have been due to the Moon's phase and position.

On the night of April 18, 1775, Paul Revere and William Dawes rode (on different routes) from Charlestown to Lexington, Massachusetts, to alert fellow patriots Samuel Adams and John Hancock that British soldiers were coming to arrest them. The events that followed ushered in the start of the American Revolutionary War, and the Moon played a critical role in both helping and betraying these Sons of Liberty.

Blinded by the light?

Revere's journey began in Boston's North End, where two friends rowed him across the narrow part of the Charles River that separates the North End from Charlestown. The crew members faced a formidable challenge: They needed to row unnoticed past the huge British ship the HMS *Somerset*, which England had stationed there to prevent any such attempt.

When Revere and his friends made the crossing at around 10 P.M., a bright waning gibbous Moon stood 6° above the east-southeastern horizon. It is possible that this was not a coincidence but instead strategy: With the Moon behind him, Revere could use its light to navigate to shore, which would have been difficult to achieve in complete darkness.

In 1798, Revere recalled in a letter to American historian Jeremy Belknap that the patriots rode "a little to the eastward where the *Somerset* Man-of-War lay." This was a brilliant strategy. When we look in the direction of a nearly Full Moon that is close to the horizon, the landscape before us becomes difficult to interpret due to intense contrast effects that create bright areas next to those deep in shadow. At the same time that the Moon's light assisted the patriots safely to shore, its enhancement of contrast must have hindered sentries on the *Somerset* from seeing the stealthy small boat.

The Moon was positioned well for a glitter path — a line of lunar reflections that appears on rippling water — to occur. That collection of reflections would have shown the sentries a rowboat in silhouette had the path not been oriented east-southeast to west-northwest — tangential to the northward path of Revere's boat. If a sentry had taken note of the rising Moon and its glitter path, his gaze would have been averted from the passing patriots. Looking at a bright Moon would have ruined his dark adaptation and adversely affected his peripheral vision's acuity.

THINKSTOCK/THERION256/ISTOCK

The waning gibbous Moon of April 18, 1775, rose low in the southeast, allowing Paul Revere to navigate his crossing of the Charles River by its light and distracting British soldiers aboard the HMS *Somerset* with its glitter path and strange contrast-inducing effects.

The Judas Moon

Once he was on horseback, Revere rode into an increasingly well-moonlit night. Around 11 P.M., when he was approaching Cambridge, he recalled that "the moon shone bright." According to his own account, he encountered "two Officers on Horseback, standing under the shade of a Tree." Before he noticed them, Revere had gotten "near enough to see their Holsters & Cockades."

This passage shows that the British troops had their own effective moonlight strategy. By avoiding direct or reflected rays from our satellite, the soldiers blended in with the forest's dappled shadows. The great difference in contrast between lit and shadowed areas created a splendid camouflage. Allied World War II pilots used a similar technique to avoid detection by enemy planes flying above them when they were passing over moonlit water.

In Cambridge, the roles were reversed from the way they had been earlier in the night. Revere now had the disadvantage of being a moving target exposed to the light of a high Moon while the British stood motionless and unperceived in the shadows. So clever was this Red Coat tactic that Revere did not notice his enemy until he could distinguish detail in their wardrobes, which means he was right on top of them. Revere was able to use his horsemanship, however, to escape. He was, unfortunately, not so lucky in Lexington, when he rode into the same shadow trap and was captured.

As Revere learned, what happens in the sky above can make or break what happens here on the ground, which is as true today as it was then.

As always, send any comments or insights to me at sjomeara31@gmail.com.

FROM OUR INBOX

COURTESY JAMES R. JOHNSON

James R. Johnson

Correction

In the December 2013 article "Speaking the language of the cosmos," the picture on p. 27 is not the James R. Johnson who was quoted. The correct James R. Johnson, who wrote *Comprehending the Cosmos, a Macro View of the Universe* (CreateSpace, 2012), is pictured here. — *Astronomy* Editors

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara.**

RENEWED SEARCH. NASA announced December 19 that its reactivated Near-Earth Object Wide-field Infrared Survey Explorer had returned its first set of images.

CHRISTINE DANILOFF/MIT/JULIEN DE WIT

READING THE RAINBOW. By looking at the spectrum of light that appears through a planet's atmosphere when it passes in front of its star, astronomers now can determine the world's mass.

Planets weighed by starlight

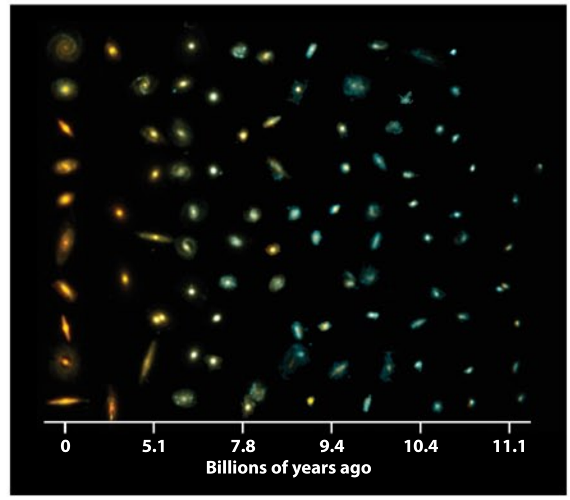
A planet's mass is more than just a number: It's a decoder ring, revealing secrets of the planet's composition, activity, and habitability. Determining this quantity, though, is not easy. For the most part, scientists calculate masses by watching planets tug their stars back and forth as they orbit, revealing their gravitational influence. However, this technique is less effective as the planets that astronomers find become smaller and orbit farther from their stars.

Scientists have found a new way to find a planet's bulk. Using the starlight that passes through the planet's atmosphere, they can measure atmospheric qualities and then use those to calculate the mass. The method was published December 20 in *Science*.

When a planet passes in front of its star, blocking light, telescopes can see a slight dip in the sun's brightness. Light passes through the atmosphere, which changes it in a way that is specific to each planet and its properties. The resulting altered light is called the "transmission spectrum."

Julien de Wit of the Massachusetts Institute of Technology figured out how to disentangle atmospheric temperature, pressure, and density from the transmission spectrum. These three properties reveal the planet's mass — just as knowing the distance a car has traveled and how long that trip took tells you the car's average speed.

De Wit and colleague Sara Seager tried his idea out on an exoplanet with an already known mass. They came up with the same result. Now, astronomers have a different tool at the ready for determining the masses of as-yet-unknown and more Earth-like planets. — **S. S.**



NASA/ESA/P. VAN DOKKUM (YALE UNIV.)/S. PATEL (LEIDEN UNIV.)/THE 3D-HST TEAM

EVOLUTIONARY EXAMPLES. By studying galaxies similar to the Milky Way at various stages of growth over a period of 11 billion years (some of which are shown here), scientists were able to produce visual evidence of how our galaxy evolved.

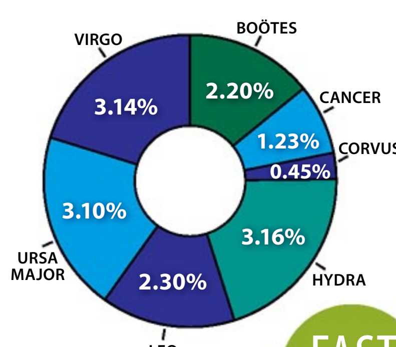
Forming a picture of Milky Way growth

Although astronomers can't go back in time to see how the Milky Way evolved into the stunning barred spiral galaxy we call home today, they can study similar stellar conglomerations at different stages of development to see if they match current models. Over the past year, a large team of scientists has used the Hubble Space Telescope's deep-sky surveys to do just that, with results appearing in the July 10 issue of *The Astrophysical Journal Letters* and the December 1 issue of *The Astrophysical Journal*.

By studying 400 galaxies similar to the Milky Way that cover various moments in a time span of 11 billion years, these astronomers have revealed the first visual evidence of how our galaxy was assembled. "By tracing the Milky Way's siblings," says study co-leader Pieter G. van Dokkum of Yale University, "we find that our galaxy built up 90 percent of its stars between 11 billion and 7 billion years ago, which is something that has not been measured directly before."

Beyond the time of greatest star formation, the astronomers found that the Milky Way's middle bulge, home to much older stars and the galaxy's central supermassive black hole, grew simultaneously with the galactic disk. "These galaxies show us the whole Milky Way grew at the same time," says co-author Erica Nelson, also of Yale, "unlike more massive elliptical galaxies, in which the central bulge forms first." — **K. F.**

HOW BIG IS THAT CONSTELLATION?



CONSTELLATIONS COMPARED. This chart shows the relative sizes of April's nighttime star patterns. Percentages give total sky coverage. *ASTRONOMY*: MICHAEL E. BAKICH AND KELLIE JAEGER

FAST FACT

The three largest constellations appear in April's sky.

25 years ago in *Astronomy*

In the April 1989 issue, Deborah Byrd's article was a question: "Do Brown Dwarfs Really Exist?" These objects are in between planets and stars, not quite hot enough to ignite fusion.

Astronomers would net their first discovery in 1995. Since then, they've found hundreds more, but the objects are more rare than once thought.

10 years ago in *Astronomy*

In the April 2004 issue, Bruce Moomaw wrote "Spirit lands at Gusev," which followed the rolling robot geologist to the Red Planet. Spirit landed on January 3, 2004.

Spirit's sibling, Opportunity, continues to return geological data 10.3 years after its arrival — and 10 years longer than it was originally scheduled to rest in peace. — **S. S.**

Dark matter first reared its head in observations of galaxy clusters, such as Pandora's Cluster (Abell 2744). This Hubble view reveals hundreds of galaxies ranging from monsters 100 times bigger than the Milky Way to dwarfs $\frac{1}{1,000}$ our galaxy's mass. NASA/ESA/J. LOTZ, M. MOUNTAIN, A. KOEKEMOER, AND THE HFF TEAM (STScI)

THE MISSING UNIVERSE

Most astronomers think unseen matter permeates the universe, but some researchers suspect we don't quite understand gravity.

by Bob Berman

Eighty-one years ago, most of the universe went missing. According to many astronomers, it's *still* missing. And it's making some of them uncomfortable.

The problem started with the famous Swiss physicist Fritz Zwicky. It was he who first theorized the existence of neutron stars. He also coined the word *supernova*. Cantankerous and crotchety, he was such a heavy hitter that everyone paid attention when his brain went *boing*.

It did exactly that in 1933 when he was studying speeds in the giant Coma galaxy cluster. What he perceived was astonishing. Each member moved so quickly, it should have had no problem escaping the gravitational glue of the entire assembly. Zwicky realized that this galaxy cluster — and all others, it soon turned out — shouldn't even exist. Yet there they were.

Extra gravity must lurk within and among the galaxies. The conclusion was bewildering: Some invisible substance boasting an enormous gravitational pull apparently dominates the universe. Zwicky called it "dark matter," and the name stuck.

Problems closer to home

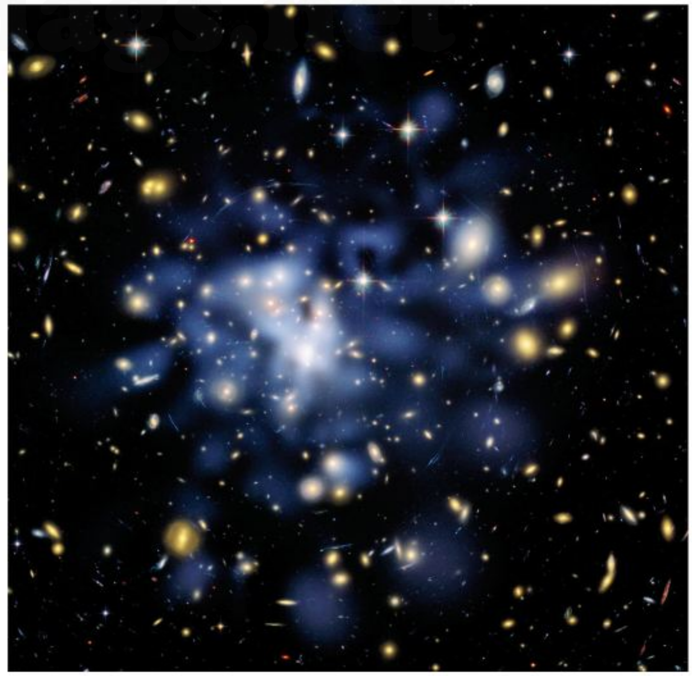
Actually, a year earlier Dutch astronomer Jan Oort had noticed the same thing on a much smaller scale in our Milky Way Galaxy. Logic demands that stars near the galactic core quickly whirl around the nucleus while stars at the edges move more slowly. The situation ought to be akin to that in our solar system, where Mercury zooms around the Sun in just three months while poor demoted Pluto requires a quarter millennium. Gravity rapidly grows weaker with distance, so objects farther away must move more slowly. But that's not what happens in our galaxy — or any other.

Except for the stars whirling frantically around the supermassive black hole near the Milky Way's core, the rest of the galaxy spins as if each star's accelerator is frozen at the same setting. The Sun orbits our galaxy's nucleus at a speed of approximately 135 miles per second (220 kilometers per second). If you visit a star much closer in or farther away, nothing changes. In other words, the galaxy's rotation curve is flat. This would happen only if the Milky Way were enveloped in an enormous ball of invisible matter containing at least a half-dozen times more mass than our entire galactic inventory.

So, within galaxies and between them, everywhere we gaze, lurks more gravity — and thus more mass — than makes sense. Scientists quickly dubbed this the "missing mass problem."

Bob Berman *is the author of the column "Strange Universe."*

Four separate galaxy clusters came together over a span of 350 million years to form Pandora's Cluster (Abell 2744). In this image, hot gas emitting X-rays has been colored red, and the deduced distribution of dark matter appears blue. NASA/ESA/J. MERTEN (INSTITUTE FOR THEORETICAL ASTROPHYSICS)/D. COE (STScI)



Hubble Space Telescope scientists mapped the expected distribution of dark matter (blue) in galaxy cluster Abell 1689 based on its gravitational effects on more distant galaxies. NASA/ESA/D. COE (JPL-CALTECH/STScI)/N. BENITEZ (INSTITUTE OF ASTROPHYSICS OF ANDALUSIA)/T. BROADHURST (UNIVERSITY OF THE BASQUE COUNTRY)/H. FORD (JOHNS HOPKINS UNIVERSITY)

It would not go away. As telescopes got bigger and astronomers observed more of the universe, the situation stubbornly endured. Years and then decades passed. Some astronomers brought up the problem from time to time; others ignored it. By and large, the major media and non-scientists shrugged it off. OK, we get it: There's more stuff than meets the eye. What's the big deal? Maybe there are more stars than we know of. Or more dust clouds. Or nebulae. Maybe all that unseen gravity lurks in black holes. Why is this so profound?

But it *is* a big deal. Stars are luminous — and massive ones especially so. There simply cannot be many unseen stars. That goes for the failed stars known as brown dwarfs as well — there aren't enough of them. Dust clouds reveal themselves by blocking or reddening everything behind them, and astronomers don't see this either. Nebulae show themselves by imposing spectral lines on the light arriving at Earth from more distant objects, so that's not the case.

As for black holes, they affect everything in their 'hood. The black hole known as Cygnus X-1 whirls in tandem with a visible star once every 5.6 days like sumo wrestlers. Black holes betray their presences. They are not there — not enough of them, anyway.

On the dark side of matter

So the problem is deep. There's far more gravity in the universe than astronomers can account for. What's creating it? What is this strange, unseen stuff?

Most astronomers assume dark matter (DM) consists of undiscovered particles that only interact anemically with planets, stars, and ourselves. Because scientists love acronyms, they call these "WIMPs," for weakly interacting massive particles.

It's not far-fetched. The universe's most common particles are neutrinos. They are invisible, too. They also are numerous and interact only weakly with normal matter. A trillion neutrinos pass through each of your fingernails every second. Yet statistically, despite their omnipresence, you'd have to wait a century before a single atom in your body was jostled by a neutrino. Even hypochondriacs ignore them.

Yet statistically . . . you'd have to wait a century before a single atom in you body was jostled by a neutrino. Even hypochondriacs ignore them.

So it's not much of a stretch to imagine a kind of souped-up neutrino. To achieve the observed gravitational effects, huge numbers of these particles would have to dwell mostly in a halo surrounding each galaxy. Meaning, galaxies are like ships in bottles, enclosed by unseen spheres. But DM also would have to lurk everywhere else, too. It would have to coexist with us, occupying the same room you are sitting in.

DM particles — unlike neutrinos, which weigh virtually nothing — would each have a mass at least that of a lead atom. Hundreds

THE KNOWN MATTER IN THE UNIVERSE

The stable of stable particles:

Heavyweights: Baryons, meaning quarks. They gather in threes, forming neutrons and protons — the stuff of normal matter.

Middleweights: Leptons, such as electrons. Each electron weighs 1,836 times less than a proton.

Lightweights: Neutrinos, which are omnipresent but weigh next to nothing.

Every particle has an antimatter twin that possesses identical properties but opposite electrical charge and other properties.

Numerous transient, unstable particles of various masses also come and go.

The gravitational pull of unseen matter likely warps the light from more distant objects in the galaxy cluster MACS 1206, although some scientists think a change to Isaac Newton's law of gravity better explains the observations. NASA/ESA/M. POSTMAN (STScI)/THE CLASH TEAM

must be passing through your body each second. They'd be the majority material in the cosmos and likely form structures. An entire DM universe would coexist with ours like a zombie empire. Yet despite their crowded presence, they must neither help us nor harm us.

A gravitational twist

Every few years, researchers think they've spied traces of WIMPs, but the hopes have never panned out. Nonetheless, most astronomers are convinced that they'll ultimately find these particles — and then we'll know what most of the material universe is made of. And that's where this story would end — if it weren't for "MOND."

Thirty-one years ago, the prestigious *The Astrophysical Journal* published three articles by Israeli physicist Mordehai Milgrom, who proposed an entirely different solution to the crazy galaxy motion problem. Instead of seeking missing mass that tugs at everything, Milgrom mathematically showed that we'd see the same effects if gravity itself behaves differently at its weakest.

A modification of Isaac Newton's law of gravity is not something many scientists were willing to accept — then or now. Yet the principle is sound: What if there's a lower limit on how weak gravity can become? What if gravity, whose strength falls off inversely with the square of the distance between two objects, operates with more oomph than expected in places where it accelerates objects most feebly — like the outskirts of galaxies? (Such a tweak would not be unprecedented — Albert Einstein showed in his general theory of relativity

Ongoing searches for dark matter include the Large Underground Xenon experiment, located in an abandoned gold mine in the Black Hills of South Dakota. LUXDARKMATTER

that in the strongest fields, gravity behaves differently from what Newton thought. And essentially no scientist doubts that fundamental change to gravity.)

If that's true, then dark matter need not exist at all.

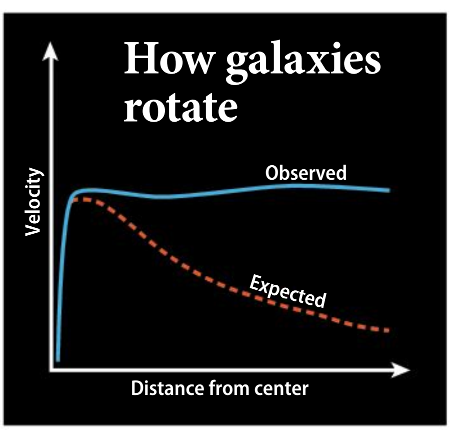
This MOdified Newtonian Dynamics (MOND) theory takes scientists to a key investigative area, something called the Tully-Fisher relation. Proposed in 1977 by American astronomers R. Brent Tully and J. Richard Fisher, it shows that the rotational speed of a spiral galaxy is related to its brightness. Luminous galaxies spin faster. This makes sense because a brighter galaxy has more stars and hence probably more mass, which defines how much gravity drives the rotation.

But finding that Tully-Fisher works with virtually all galaxies, even when their surface brightnesses (the average glow from an object's total area) vary, supports MOND theory better than it supports the existence of dark matter. Indeed, the rotation curves align so well for MOND that some former DM supporters, like astronomer Stacy McGaugh at Case Western Reserve in Cleveland, left the congregation.

"I believed in dark matter as much as anybody," McGaugh says. "In fact, since we all called the whole thing 'the missing mass problem,' we were predisposed toward the dark matter solution. But which is simpler — a new kind of particle that fits nowhere in the standard model of particle physics and shows itself more in some places than others? And for which there's no evidence at all? Or, instead, simply sticking with a single force — gravity — that behaves a bit differently from what we thought?"

McGaugh and other members of the MONDian minority have a point. Of the four fundamental forces in the universe, gravity is the most mysterious. No one knows why it is the way it is, and there's no absolute reason — no writing on stone tablets — that it must fall off with the inverse square at every possible level of strength or acceleration.

"Years ago, in trying to make dark matter work, I had to add all sorts of patches and assumptions when dealing with varying galaxy surface brightnesses," McGaugh says. "With dimmer surfaces, dark matter just couldn't fit. I tried to make it work, but the data apparently didn't get that memo. I found I was simply adding epicycles." He chuckled at that image, which alludes to 16th-century and earlier efforts to make planet orbits fit an Earth-centered doctrine.



ASTRONOMY: ROEN KELLY

A galaxy's rotation curve compares the velocities of stars in the disk with their distances from the galaxy's center. Observed curves appear flat, suggesting that a halo of unseen matter or gravity behaves differently in weak fields. Without dark matter or Modified Newtonian Dynamics, the curve would drop off at increasing distances.

FIVE STATES OF MATTER

Matter can exist either as a plasma, gas, liquid, solid, or Bose-Einstein condensate.

Quarks combine into protons and neutrons to form atomic nuclei held together by the strong force, and these can join with electrons into atoms held together by the electromagnetic force.

A cloud of electrically charged atomic nuclei (ions) and electrons is a **plasma**.

When atoms float loose, they form a **gas**.

When atoms attach weakly to neighbors, they form matter's rarest state, a **liquid**.

When atoms rigidly bond to neighbors, they constitute a **solid**.

At temperatures colder than any natural place in the universe, atoms can merge spookily into a single state, the **Bose-Einstein condensate**.

Moreover, says McGaugh, "With dark matter, there's nothing in it you can't fudge. You have endless freedom to try to make it fit. One group ran a thousand simulations and simply picked the one that worked."

Test the nearly untestable

It is true that MOND does away with the need for an entirely new form of matter. Nonetheless, a true MOND test would require placing an experimental apparatus far from any gravity field.

"We'd need to go about a tenth of a light-year from Earth, or 7,000 astronomical units [AUs, or Sun-Earth spans]," says McGaugh, sighing. He knows this is as likely as teaching cats to learn their own names. No space probe will venture anywhere near that far in our lifetimes. The farthest Voyager spacecraft, for comparison, now lies 127 AU away.

A fly in the ointment?

But MOND enthusiasm comes with caveats. Why gravity should have this low-intensity anomaly is anyone's guess. Moreover, MOND works well in predicting how galaxies rotate, but it doesn't work as well in explaining motions at much larger scales, such as those between galaxy groups. So, most astronomers remain in the DM camp.

One of them is astrophysicist Hongsheng Zhao at the University of St. Andrews in the United Kingdom. He compares the

The Whirlpool Galaxy (M51), like all other spirals, seems to possess about 10 times more gravity than its visible contents can account for. Either dark matter surrounds these galaxies or gravity operates differently than most scientists think.
NASA/ESA/S. BECKWITH (STScI)/THE HUBBLE HERITAGE TEAM (STScI/AURA)

current battle between the two camps to a four-dimensional board game, with MOND owning the within-galaxy territory and DM calling the shots on the largest scales. He concedes that for his beloved DM to work within dense star concentrations like globular clusters, the theory would have to "appeal for some magic." But Zhao believes DM's alternative fails on the largest scales: "MOND predicts galaxy clusters should behave as if just the known stars and nebulae influenced their motions — which is wrong by a factor of 10."

"It's more like a factor of two," McGaugh says in rebuttal. But either way, MOND doesn't really shine once you're floating beyond the galaxies.

These two opposing researchers are witty and gentle. But that's not the case everywhere. Much emotion and tension exist over this issue. Many DM advocates regard MOND as akin to a flat-Earth hypothesis. Yet it also appears some are unaware of powerful recent evidence that points MONDward.

"With dimmer surfaces, dark matter just couldn't fit. I tried to make it work, but the data apparently didn't get that memo." — Stacy McGaugh

For example, McGaugh wrote a paper that appeared in *The Astronomical Journal* in 2012 showing that low-mass galaxies fall along the Tully-Fisher relation precisely as MOND predicts. That was new, unexplored territory; it didn't have to work out so. Better still, the data "scatter" is negligibly small, posing another fine-tuning problem for DM models.

Then, too, in 2013 the rotation curves for the Andromeda Galaxy's recently discovered dwarf spheroidal satellites matched MOND predictions. Last year also brought proof that Milky Way stars hovering far above and below the galaxy's disk move in accordance with MOND. They don't seem the least nudged by all the theoretical DM that supposedly occupies that very region.

Put it all together, and the odd-gravity MOND idea certainly seems compelling, at least in our neighborhood. At the largest scales, so does DM, although its advocates do take more parameter-tweaking liberties to make the data fit.

The food fight between the two sides is likely to rage for years. It will end with finality only if scientists actually discover DM particles, or some as-yet-undreamt-of gravity experiment clinches MOND.

Until then, astronomers can only keep gazing into the night sky, conducting their experiments, and wondering, as Zwicky did 81 years ago, whether most of the cosmos is really missing.

READ MORE ABOUT ASTRONOMERS' SEARCH FOR DARK MATTER AT **www.Astronomy.com/toc.**

Powerful particles

Every day, quintillions of atomic nuclei strike Earth's atmosphere at nearly the speed of light. What natural particle accelerators are powerful enough to produce such high-energy cosmic rays? **by Angela Olinto**

Solving the mystery

The origin of the most energetic particles in the universe is a mystery. They belong to a family of objects called cosmic rays — protons, other nuclei, and the occasional electron that rocket through space at nearly the speed of light. They cover long cosmic distances and eventually arrive on Earth, coming from all directions. But what boosts them to such extreme energies? After more than a century of wondering, scientists have built detectors in space and on the ground that have begun to unveil long-awaited answers.

Ray research

But learning more about cosmic rays isn't easy. Astronomy is based on observing different wavelengths of light that come from space — from the longest radio waves to the shortest gamma rays — and all travel the straightest possible paths to our telescopes. Unlike light, which is neutral, cosmic rays are electrically charged, which causes their paths through space to be more complicated. Magnetic fields that permeate our solar system, galaxy, and universe twist their routes, erasing information about the direction they came from. Without a line pointing back into space, cosmic-ray scientists must use other clues to unveil the particles' sources.

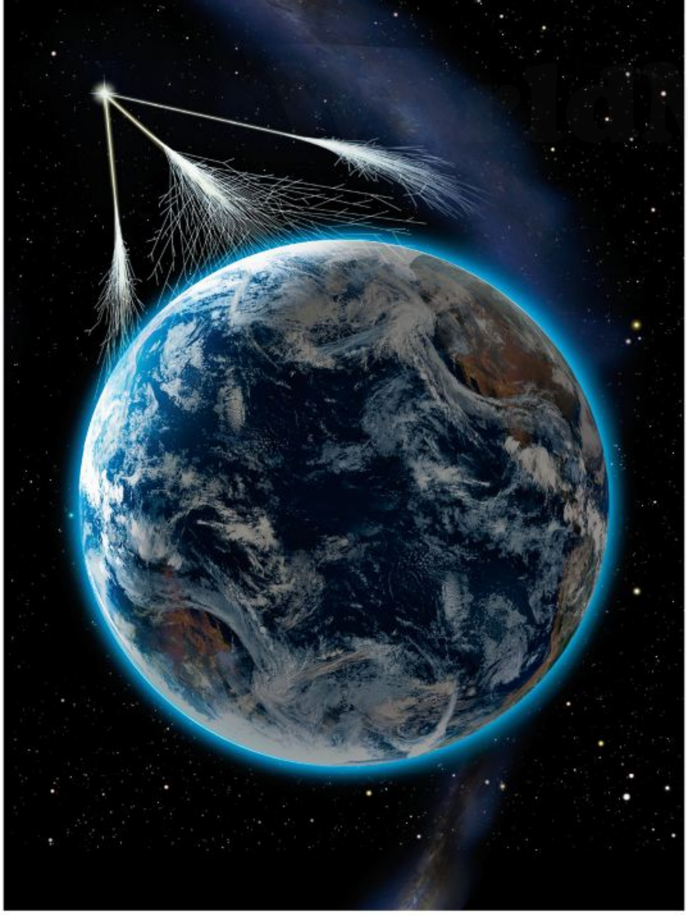
Chief among those hints are the rays' rates of arrival on Earth and their composition, both as compared to their energies. Cosmic rays arrive with energies that span 12 orders of magnitude: The highest-energy particle packs a trillion (12 zeros) times more

Angela Olinto *is the chair of the University of Chicago Astronomy and Astrophysics department.*

# of COSMIC RAYS

In 2013, astronomers finally nailed down the origin of galactic cosmic rays. By observing two supernova remnants, including IC 443 (shown), they found signatures of cosmic rays fleeing the scene. This breakthrough is the first definitive evidence of any specific particle accelerator besides the Sun.

CHANDRA X-RAY: NASA/CXC/B. GAENSLER, ET AL.; ROSAT X-RAY: NASA/ROSAT/ASAOKA & ASCHENBACH; RADIO: NRC/DRAO/D. LEAHY; OPTICAL: DSS



When cosmic rays crash into Earth's atmosphere, they collide with its molecules, breaking into a cascade of less energetic particles in a process called an air or particle shower. *ASTRONOMY:* ROEN KELLY

A PARTICLE PHYSICS DETOUR

Researchers' early investigations of cosmic rays led to discoveries in other fields. From 1933 to 1953, scientists found new particles while investigating these tiny beasts. In 1933, American physicist Carl Anderson discovered the positron — the anti-electron, the first antimatter particle to be identified — while watching tracks that cosmic rays left in a cloud chamber. In 1937, the muon was discovered, followed by the pion, the kaon, and the lambda. Each showed nature's building blocks to be more complex.

By the early 1950s, the study of the fundamental nature of matter and its interactions moved from cosmic rays — naturally accelerated objects — to those produced in man-made particle accelerators. By the mid-1970s, Sheldon Glashow and Steven Weinberg of Harvard University and Abdus Salam of Imperial College London had formulated the standard model of particle physics, a theory of how the electromagnetic, weak, and strong fundamental forces interact with matter. New instruments like the Large Hadron Collider (LHC) on the Switzerland-France border now can test most of the standard model's predictions to see if the theory is true, but even this advanced technology has a limit. Cosmic rays, on the other hand, can reach higher energies than machine-accelerated particles. Some have energies more than 10 million times those of the LHC, giving humans a laboratory more powerful than one we built for ourselves. — *A. O.*

punch than the lowest-energy one. The number of cosmic rays that arrive over a period of time — known as flux — varies depending on that energy level. The more energetic a particle is, the more rare it is. Several low-energy cosmic rays bombard every square inch of Earth every second, while the extremely energetic ones arrive in a whole square-mile area only once per century. With such a diverse population to study, scientists have adopted a variety of observational approaches.

When cosmic rays enter Earth's atmosphere, they collide with its molecules. This crash generates a cascade of secondary particles — called an air or particle shower — whose identities hide those of their cosmic-ray parents. Balloon and space missions, which float or orbit above most atmospheric molecules and thus above the particle showers, can detect primary cosmic rays. Ground detectors, on the other hand, use the characteristics of the particle cascades to rewind the event and infer the kinds of cosmic rays that caused them. Both types of observations show that cosmic rays are atoms stripped of their electrons — nuclei from hydrogen (which are just protons), helium, carbon, oxygen, iron, and even heavier elements.

These nuclei have been accelerated to relativistic energies — meaning they travel close to the speed of light — by natural particle accelerators. But what, exactly, these accelerators are and how, exactly, they act as such powerful boosters is a century-old mystery.

Radiation from above

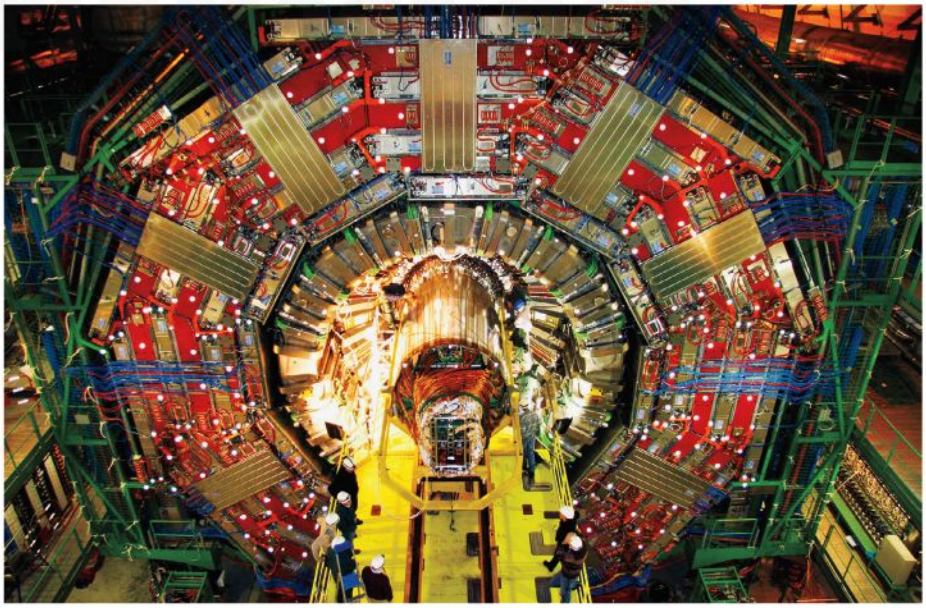
The idea that some form of ionizing radiation — fast-traveling charged particles that can knock electrons out of their atoms — exists throughout space dates back to 1785. That year, French physicist Charles-Augustin de Coulomb found that electroscopes, which detect an object's charge, spontaneously lost their own charge even if they were well-insulated. At the end of the 19th century, the discovery of radioactivity gave a partial answer about why: Radioactive materials produce energetic particles (then simply called "rays") that crisscross space. When they collide with an electroscope, they cause its charge to dissipate as they knock its electrons away. By 1911, scientists had taken electroscopes into tunnels, underwater, and in between metal shields to learn more about this penetrating radiation. Was it coming from Earth's crust, the atmosphere, or somewhere beyond our planet?

Austrian physicist Victor Hess answered this question in 1912 by carrying electroscopes on balloon flights that reached an altitude of 3.3 miles (5.3 kilometers). Hess found that as the detectors ascended, the flux of radiation decreased immediately above the ground and didn't begin to increase again until around 0.6 mile (1.0km) in height. Then, between 2.5 and 3.3 miles (4.0 and 5.3km), the rate of radiation reached twice that observed at sea level. He called this radiation *höhenstrahlung*, which means "radiation from above." His experiments showed that although some ionizing radiation comes from the ground, most of it intrudes from space. In 1936, Hess received the Nobel Prize in physics for this discovery that ionizing radiation is extraterrestrial in origin.

After World War I, the focus of cosmic-ray research moved to the United States, where physicists Robert Millikan and Arthur Compton famously debated the nature of cosmic rays. Their argument was featured on the front page of *The New York Times* on December 31, 1932. Millikan was convinced that the ionizing radiation was composed of energetic light particles (photons) called gamma rays. He proposed that they were a byproduct of hydrogen fusion in intergalactic space and coined their name: cosmic rays. Compton, on the other hand, argued that the ionizing radiation was charged, unlike gamma rays. Although Millikan's name stuck, Compton's idea was the correct one.

A world traveler's earlier work ultimately settled this debate. In 1927, Dutch scientist Jacob Clay schlepped from Java, Indonesia, to Genoa, Italy. During his trip, he observed that cosmic-ray flux wasn't the same everywhere — it varied with latitude. To study this effect further, Compton enlisted some one hundred scientists

In 1911–1912, Victor Hess took balloon flights into the atmosphere to investigate the origins of cosmic rays. He discovered that while some came from the ground, the majority were extraterrestrial in origin. AMERICAN PHYSICAL SOCIETY



Particle accelerators like the Large Hadron Collider allow scientists to investigate high-energy phenomena, but they don't come close to natural accelerators' abilities. Cosmic rays give astronomers access to energy regimes otherwise unreachable. CERN/LHC

throughout the world to measure the flux in different locations. If cosmic rays are charged particles, he postulated, Earth's magnetic field would deflect them, leading to varying results at varying latitudes — exactly what he and his scientist volunteers saw.

Mystery solved?

Cosmic rays are of great interest not only to particle physicists but also to astrophysicists, who are curious to understand how an astronomical source can impart such extreme speeds to subatomic particles and how these particles affect cosmic and biological systems.

In 1934, German astronomer Walter Baade and Swiss astronomer Fritz Zwicky suggested that supernovae alone produced enough energy to explain the observations. Their idea was finally confirmed in 2013 when astronomers combined data from the NASA Fermi Gamma-ray Space Telescope and the Italian Space Agency's Astro-rivelatore Gamma a Immagini Leggero satellite. Two supernova remnants, W44 and IC 443, display a smoking-gun signal that proves cosmic rays emerge from their edges. And based on this new work, astronomers can look back and see that the history of supernovae in our galaxy paints a consistent picture — one that could explain the cosmic-ray distribution we see today.

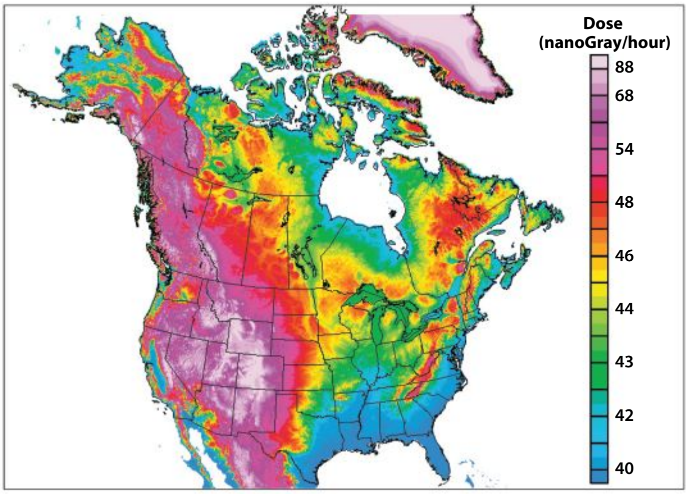
After supernova remnants accelerate them, cosmic rays diffuse around the Milky Way for long periods of time. With their magnetically twisted paths, they take tens of millions of years to reach Earth — and the lower their energy, the longer they take — while a similar neutral particle would take just 100 millennia to cross the extent of our galaxy, as it would travel in a straight line.

Scientists learn more about the rays' magnetic diffusion by measuring the relative abundances of cosmic-ray nuclei with different energies. A trailblazing program of experiments in short- and long-duration balloons and space missions has made great progress in understanding the history of cosmic rays in our galaxy.

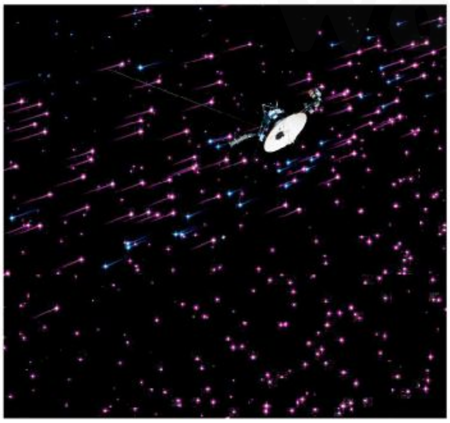
These experiments have found that common nuclei are much more abundant in their cosmic-ray form than they are in their slower forms, as part of the solar system's ingredients. Lithium, beryllium, and boron nuclei, for example, are 100,000 times more abundant in cosmic rays than they are in the solar system. The components of the universe should be approximately the same everywhere. This overabundance, then, shows that heavy-nuclei cosmic rays must have collided with interstellar material and broken down into these smaller particles. Based on these demographics, astronomers can tell the average density of the space through which cosmic rays have passed. Our analysis suggests that the rays have trajectories of millions of light-years — longer than the thickness of the galactic disk, which is just thousands of light-years tall.

Galactic cosmic rays cover at least eight orders of magnitude on the cosmic-ray spectrum. At lower energies, protons dominate the spectrum, while heavier elements up to iron rule at higher energies. Astronomers expect this transition to heavier elements because galactic cosmic rays travel meanderingly in the Milky Way's magnetic field. Their probability of escape depends on the ratio of their

Cosmic-ray exposure

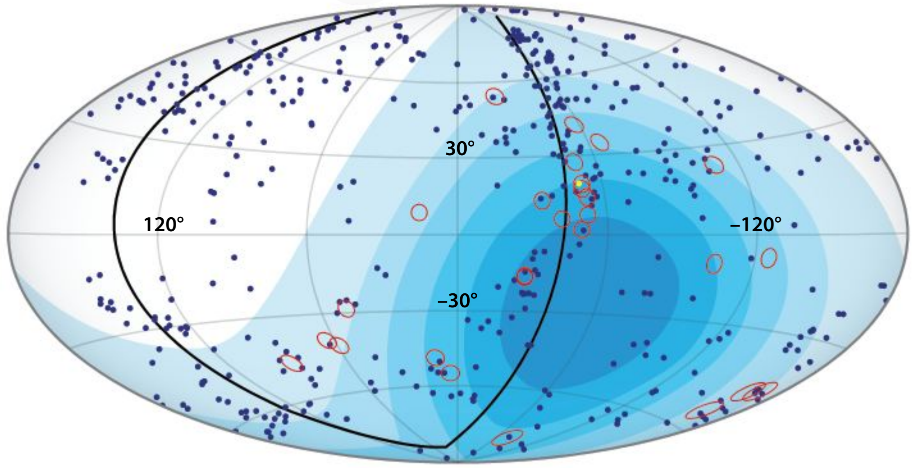


The more elevated a location is, the more cosmic rays and secondary particles make it through the atmosphere and smash into the ground. The Rocky Mountains receive the most rays per year in the United States, while low-lying states like Florida receive few. *ASTRONOMY*: ROEN KELLY, AFTER BOLTNEVA, NAZAROV, AND FRIDMAN (1974)/USGS



The Voyager 1 spacecraft is the man-made object farthest from Earth. In August 2012, it entered interstellar space. But before that, in May 2012, it saw the telltale decrease in cosmic rays from the Sun and an increase in those from outside the solar system, signaling that it was leaving the Sun's magnetic influence. NASA/JPL-CALTECH

The biggest cosmic-ray hits



Ultra-high-energy cosmic rays do not come equally from all directions in the sky, which gives scientists clues about their origins. The red circles show such detections from the Pierre Auger Observatory.

PIERRE AUGER OBSERVATORY/CRONIN (2007)/ABRAHAM (2007)

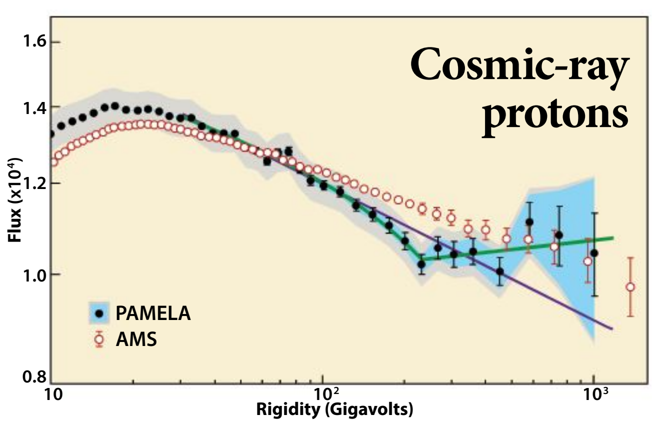
energy to their charge, and heftier nuclei, like heftier macroscopic objects, have more energy than light ones when they are traveling the same speed.

While cosmic rays with intermediate energies come from supernova remnants within the Milky Way, those with the lowest energies come from the Sun and are called solar particles.

To the edge ... and beyond

Different observational techniques allow scientists to find cosmic rays over 12 orders of magnitude in energy: from below 10^8 electron volts (eV) to just above 10^{20} eV, where 1 eV is the amount of energy an electron gains by crossing 1 volt of potential. For comparison, a molecule that is at room temperature has approximately 0.04 eV of energy.

Balloon and space experiments can detect the cosmic rays directly up to 10^{15} eV, but above that, the rate is too low, so scientists instead observe the air showers of secondary particles they create. For direct detection, the International Space Station (ISS) hosts instruments that wait for bombarding cosmic rays. The Alpha Magnetic Spectrometer (AMS) is the first, and it currently is making precise measurements of the composition and spectrum of different types of cosmic rays over a range of energies.



ASTRONOMY: ROEN KELLY, AFTER CERN/AMS

The Alpha Magnetic Spectrometer (AMS) detects cosmic rays across a range of energies. Its results improve upon those of its predecessor, the Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA). The purple and green lines represent the models that best fit the observations.

Two new cosmic-ray detectors will join AMS at the ISS in 2014, the CALorimetric Electron Telescope and ISS-Cosmic Ray Energetics And Mass. These major international efforts have the sensitivity to clarify the nature of galactic cosmic rays and possibly discover some previously unknown components of the spectrum of cosmic radiation.

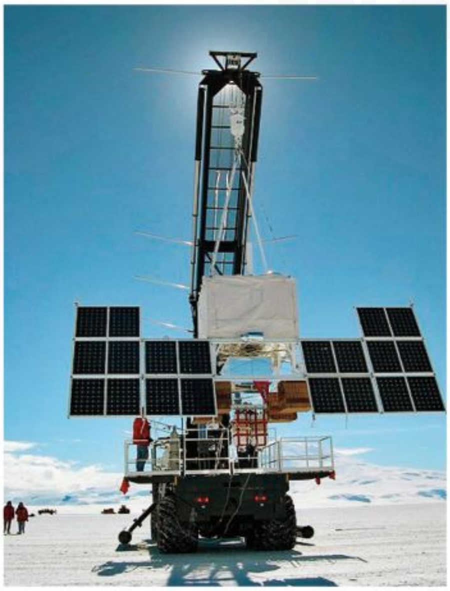
The most enduring space explorers of cosmic rays, however, are the 36-year-old Voyagers 1 and 2. Voyager 1 launched September 5, 1977, a few weeks after the launch of its twin, Voyager 2. In their epic visits to the outer planets and beyond, they have sent us cosmic-ray detections from the farthest sites in the solar system. In August 2012, Voyager 1 became the first man-made object to send signals from interstellar space. Cosmic-ray signals guide scientists' understanding of these interstellar boundaries. The Sun's magnetic influence keeps solar wind particles confined to the solar system and keeps some of the galactic cosmic rays from entering. The announcement of Voyager 1's crossing into interstellar space involved a drop in the flux of solar cosmic rays and a jump in the flux of galactic ones. Now, Voyager 1 has become the first to interact directly with the lowest-energy galactic cosmic rays, which were out of reach before.

Ultra-high-energy rays

At energies above approximately 10^{17} eV, extragalactic cosmic rays — those that come from outside the Milky Way — dominate and lighter elements are more plentiful.

The precise energy where the extragalactic component takes over the galactic component is still an open question. Other mysteries also remain, such as the source of these ultra-high-energy extragalactic particles. Are they produced in supermassive black holes in the centers of distant galaxies? Or perhaps in shock waves that result when the largest structures in the universe collide or merge? Or are they, too, accelerated in the explosive deaths of the massive stars that create black holes and neutron stars? Finally, exactly how powerful can cosmic rays become?

John Linsley, an American physicist and pioneer in reaching for the highest energies, observed a 10^{20} eV cosmic-ray event in 1962 using a large detector array at Volcano Ranch in New Mexico. This minute subatomic particle had the same energy as a fast tennis ball serve. Four years later, American physicist Kenneth



NASA

In 2014, the International Space Station will host this scope, called the Cosmic Ray Energetics And Mass instrument, which will search for cosmic rays. It is part of a new generation of instruments investigating these high-energy particles.

In 2013, scientists discovered that cosmic rays — charged particles traveling near the speed of light — get their energy by crossing back and forth over the edges of supernova remnants. These shells of gas and plasma are the leftovers of massive stars that explode as supernovae, such as N 63A (shown). The origins of the highest-energy cosmic rays, though, remain a mystery. NASA/ESA/HEIC/HUBBLE HERITAGE TEAM (STScI/AURA)

PIERRE AUGER OBSERVATORY

The Pierre Auger Observatory in Argentina is dedicated to detecting cosmic rays, specifically the highest-energy ones. It has 1,600 detector tanks on the ground, like the one shown, as well as telescopes that look up to see air showers.

Greisen along with Georgiy T. Zatsepin and Vadim A. Kuzmin of the Soviet Union predicted there should be relatively fewer cosmic rays around 10^{20} eV compared to the normal decrease in flux as energy increases because of their interactions with the then newly discovered cosmic microwave background, the relic radiation from the Big Bang. In his landmark 1966 article, Greisen announced that determining exactly how the flux steepens would clarify the origin of ultra-high-energy cosmic rays.

Scientists use two main instruments to detect ultra-high-energy cosmic rays: ground arrays and fluorescence telescopes. Ground arrays sample air showers as secondary particles reach the ground and slam into detectors. Fluorescence observatories, which look above the ground, detect the ultraviolet light that nitrogen molecules in the atmosphere produce as the air shower develops. Fast and sensitive cameras record the light, equivalent to that of a household bulb moving at the speed of light tens of miles away. The fluorescence technique was pioneered at the Fly's Eye detector in Utah, which in 1991 observed a record-holding event with an energy of 3×10^{20} eV, challenging the prediction by Greisen, Zatsepin, and Kuzmin.

The relative abundance of cosmic rays of a certain high energy was recently settled by the High Resolution Fly's Eye in Utah and the Pierre Auger Observatory. Located in the Mendoza province of Argentina, the Auger Observatory is the largest detector, covering an area of 1,160 square miles (3,000 square km) with an array of water tanks called Cherenkov detectors and four fluorescence telescopes overlooking the array. The Auger Observatory also announced that ultra-high-energy particles don't come equally from all over the sky, but favor some spots over others. This inhomogeneous distribution could be the first sign of the mysterious extragalactic sources. Scientists may be able to match up the rays' locations on the sky with known objects. For example, the cosmic rays' directions may match up with active galaxies' coordinates.

Scientists recently completed another ground array called the Telescope Array Project. It covers 270 square miles (700 square km) in Utah and acts as the Northern Hemisphere complement to the southern Auger Observatory.

A new generation of observatories is also in the works, and the objective is accumulating enough extreme particles to solve the mystery behind what is shooting these ultra-high-energy cosmic rays into space. The highly sensitive Japanese Experiment Module-Extreme Universe Space Observatory fluorescence telescope, for example, will be installed on the ISS so that it can look down, using Earth's own atmosphere as a giant particle detector.

Scientists study cosmic rays with such intensity partly because the investigations lead to discoveries in particle physics and astronomy. But they also are interested because these energetic particles have changed Earth's history and the history of biology on the planet. In fact, life might not have arisen without them. When cosmic rays ionize the atmosphere, they can trigger lightning and influence cloud formation, which could have helped warm the primordial soup of our planet. They may have influenced life in other ways, too, triggering genetic mutations and catalyzing evolution.

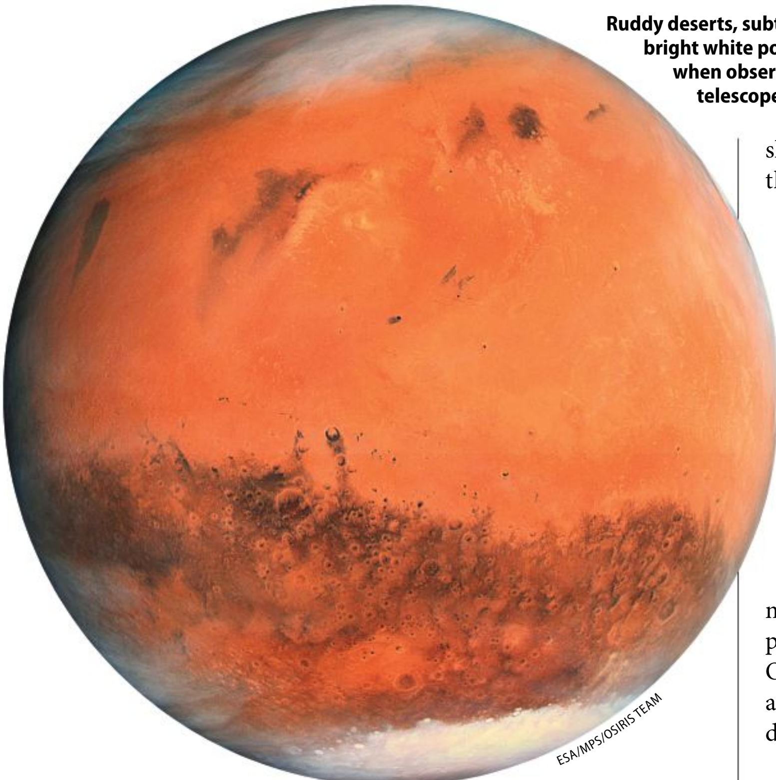
Even though cosmic rays may have helped early life, they will pose a problem in our future. As humans leave Earth's atmosphere, the flux of the rays increases, posing one of the most challenging hurdles for long-distance human space exploration. Knowledge from the new instruments, though, will help us overcome these hurdles and travel safely through space.

A+ TO LEARN MORE ABOUT COSMIC-RAY OBSERVATORIES PRESENT AND FUTURE, VISIT **www.Astronomy.com/toc.**

MARTIN RATCLIFFE and **ALISTER LING** describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

April 2014: Mars reaches its peak



Ruddy deserts, subtle dark markings, and a bright white polar cap will vie for attention when observers target Mars through their telescopes at the planet's peak this month.

The first of 2014's two total lunar eclipses occurs at the midpoint of this action-packed month. April's other highlights include Mars reaching opposition and shining brighter than at any time in the past eight years, fine views of Jupiter in the evening and Saturn later at night, and Venus sliding past Neptune shortly before dawn.

As darkness falls April 1, **Jupiter** rides above the southwestern horizon. It stands more than 60° high from mid-northern latitudes and doesn't set until after 2 A.M. local daylight time. Even by April's close, the solar system's largest planet remains on view past midnight. Jupiter shines at magnitude –2.1 at midmonth and appears brighter than any other point of light in the evening sky.

The giant planet's high altitude after sunset provides observers with two to three hours of prime viewing through their telescopes. Although Jupiter's apparent diameter shrinks from 38" to 35" during April, it's plenty big enough to show exquisite detail. Look for a series of alternating bright zones and darker belts that run parallel to the planet's equator. The most pronounced atmospheric activity tends to occur near the edges of these belts. The Great Red Spot appeared conspicuous earlier this year and should stand out if it lies on the Earth-facing hemisphere.

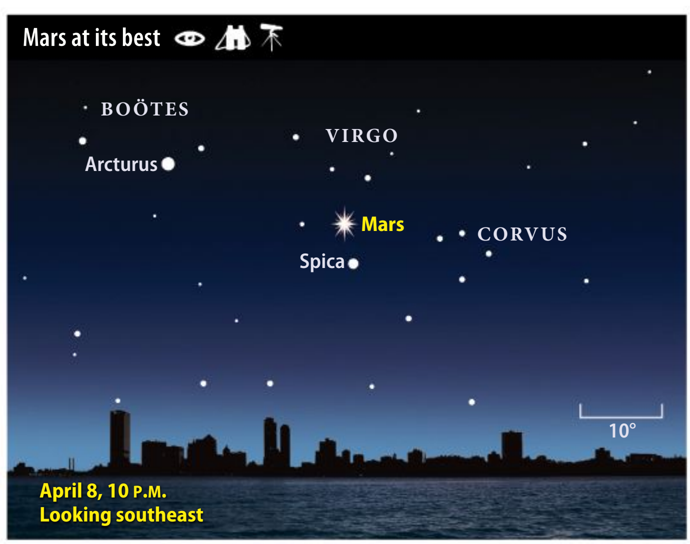
Jupiter's four bright moons put on a dynamic show through any telescope. An especially cool alignment occurs the evening of April 21. Shortly after 11 P.M. EDT, three of the moons — Io, Europa, and Callisto — form a perfectly straight line just west of Jupiter. Although the planet's moons line up frequently, most times they string out parallel to the jovian equator. On the 21st, the three moons are arrayed nearly perpendicular to the equator.

If you start watching a few minutes before 11 P.M. EDT, you'll see Io's eastward motion carry it directly between Europa and Callisto. The precise alignment lasts no more than 15 minutes centered around 11:15 P.M. EDT. (As a bonus, Europa's shadow falls on the jovian cloud tops throughout this period.)

As Jupiter sinks in the west, **Mars** rises in the east in the company of Virgo the Maiden. The Red Planet reaches opposition April 8, when it rises near sunset and appears highest in the south around 1 A.M. local daylight time. It then shines at magnitude –1.5, brighter than it has since December 2007 and marginally more brilliant than the sky's brightest star, Sirius.

The Red Planet comes closest to Earth six days after opposition. It then appears 15.2" across through a telescope, though its diameter doesn't drop below 14.6" all month. The negligible difference means that any telescope with excellent optics should deliver nice views, particularly during moments of good seeing when the air above is steady and the stars don't seem to twinkle. Because light from Mars passes through less of Earth's

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*



Look for brilliant Mars in the southeastern sky after darkness falls. The Red Planet lies in Virgo, not far from the bright star Spica. *ASTRONOMY*: ROEN KELLY

RISINGMOON

Two large craters dot the lunar crescent

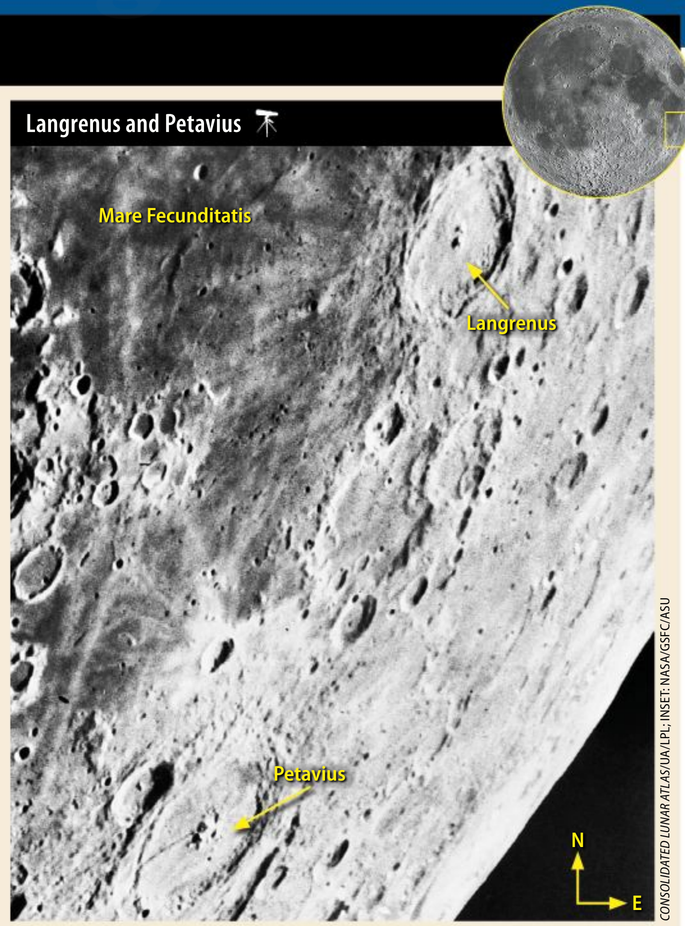
Moon observers love spring. Northern Hemisphere skywatchers have unparalleled views of the thin lunar crescent resplendent with earthshine perched in an indigo sky above a horizon of fiery orange. Through a telescope, the large crater walls and peaks that lie near the limb cast long shadows, delighting both novices and selenophiles (or lunatics, as friends call them). The enjoyment lasts awhile, too, because the steep angle of the ecliptic to the western horizon places the Moon high in the twilight sky.

Expect great views the evening of April 2, when the Sun's rays just catch the central peaks and western walls of the large craters Langrenus and Petavius. Langrenus, which spans 82 miles, is not as young as the better-known craters Copernicus and Tycho, but its features appear relatively sharp. Look for a couple of central mountain peaks and their slumped walls.

Petavius lies to Langrenus' south and is a bit bigger (110 miles across), a bit older, and sports extra features. Its rim appears softer, a telltale sign that it has spent more time under bombardment from solar system rubble. Its most intriguing feature is a large radial fracture that runs southwest from a complex cluster of central peaks. Look closely, and you also should be able to pick up a curved crack closer to the rim. Both of these fractures formed when lava from below heaved up the floor and later subsided. Junior bakers see these effects in their pie crusts if they have not learned to vent the steam.

On April 3, Mare Fecunditatis (the Sea of Fertility) appears in its entirety. The next evening, the view will appear similar to the photograph at right.

Langrenus and Petavius



CONSOLIDATED LUNAR ATLAS/UA/LPL; INSET: NASA/GSFC/ASU

The waxing crescent Moon features the conspicuous craters Langrenus and Petavius along the eastern shore of Mare Fecunditatis.

atmosphere when it lies higher in the sky, the best observing should come in the hours around midnight.

What can you see on the martian surface? The one constant will be the north polar cap. This bright white region appears prominent because the planet's north pole currently tilts about 23° in our direction, and the cap's carbon-dioxide ice reflects most of the sunlight that hits it. It is now early summer in Mars' northern hemisphere, so you should be able to see the cap shrink during April.

The rest of the martian disk presents more subtle charms. The surface markings visible depend largely on when you observe. Because Mars rotates once every 24.7 hours, features appear to

— *Continued on page 42*

METEORWATCH

April's shower fights a Last Quarter Moon

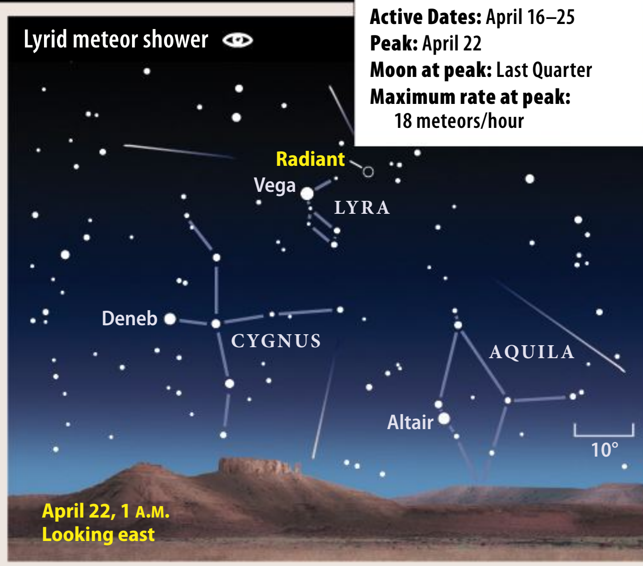
A bright Moon hinders this year's Lyrid meteor shower, which peaks April 22. Our satellite reaches Last Quarter phase the same morning, rising around 2 A.M. local daylight time. The best show should come in the hour before then.

If you stay out later, you still may witness a few bright Lyrids. The shower's radiant — the point from which the meteors appear to emanate — in Lyra passes nearly overhead just before dawn. A bright meteor would be a fitting climax to a night spent viewing the wonders of Mars and Saturn.

Lyrid meteors

Active Dates: April 16–25
Peak: April 22
Moon at peak: Last Quarter
Maximum rate at peak: 18 meteors/hour

Lyrid meteor shower



The best views of this month's premier shower will come before the Moon rises around 2 A.M. local daylight time April 22. *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT The first total lunar eclipse since December 2011 brings 78 minutes of totality to observers across the Americas and the Pacific Ocean.

STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight April 1
11 P.M. April 15
10 P.M. April 30

Planets are shown at midmonth

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

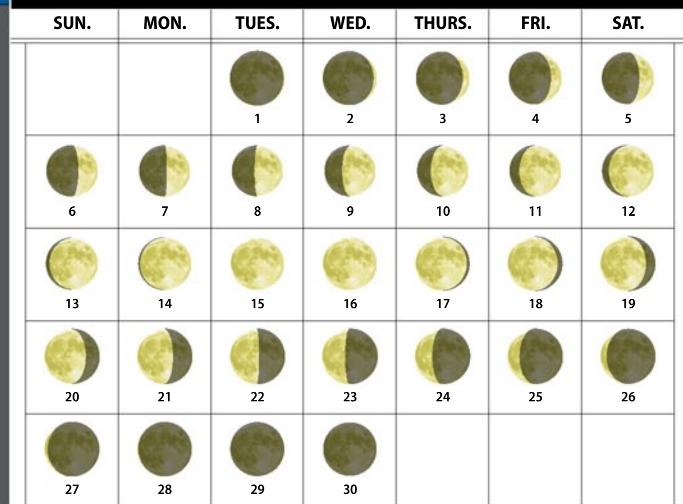
- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

APRIL 2014

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.



ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Calendar of events

2 Uranus is in conjunction with the Sun, 3 A.M. EDT

6 The Moon passes 5° south of Jupiter, 7 P.M. EDT

7 First Quarter Moon occurs at 4:31 A.M. EDT

8 The Moon is at apogee (251,344 miles from Earth), 10:52 A.M. EDT

Mars is at opposition, 5 P.M. EDT

SPECIAL OBSERVING DATE

8 Mars reaches its 2014 peak, shining at magnitude –1.5 and appearing 15" across through a telescope.

11 Asteroid Juno is in conjunction with the Sun, 3 A.M. EDT

12 Venus passes 0.7° north of Neptune, 4 A.M. EDT

13 Asteroid Vesta is at opposition, 8 A.M. EDT

14 Mars comes closest to Earth (57.4 million miles away), 9 A.M. EDT

The Moon passes 3° south of Mars, 2 P.M. EDT

Pluto is stationary, 9 P.M. EDT

15 Asteroid Ceres is at opposition, 2 A.M. EDT

Full Moon occurs at 3:42 A.M. EDT; total lunar eclipse

17 The Moon passes 0.4° south of Saturn, 3 A.M. EDT

22 Last Quarter Moon occurs at 3:52 A.M. EDT

Lyrid meteor shower peaks

The Moon is at perigee (229,761 miles from Earth), 8:24 P.M. EDT

24 The Moon passes 5° north of Neptune, 6 P.M. EDT

25 The Moon passes 4° north of Venus, 7 P.M. EDT

Mercury is in superior conjunction, 11 P.M. EDT

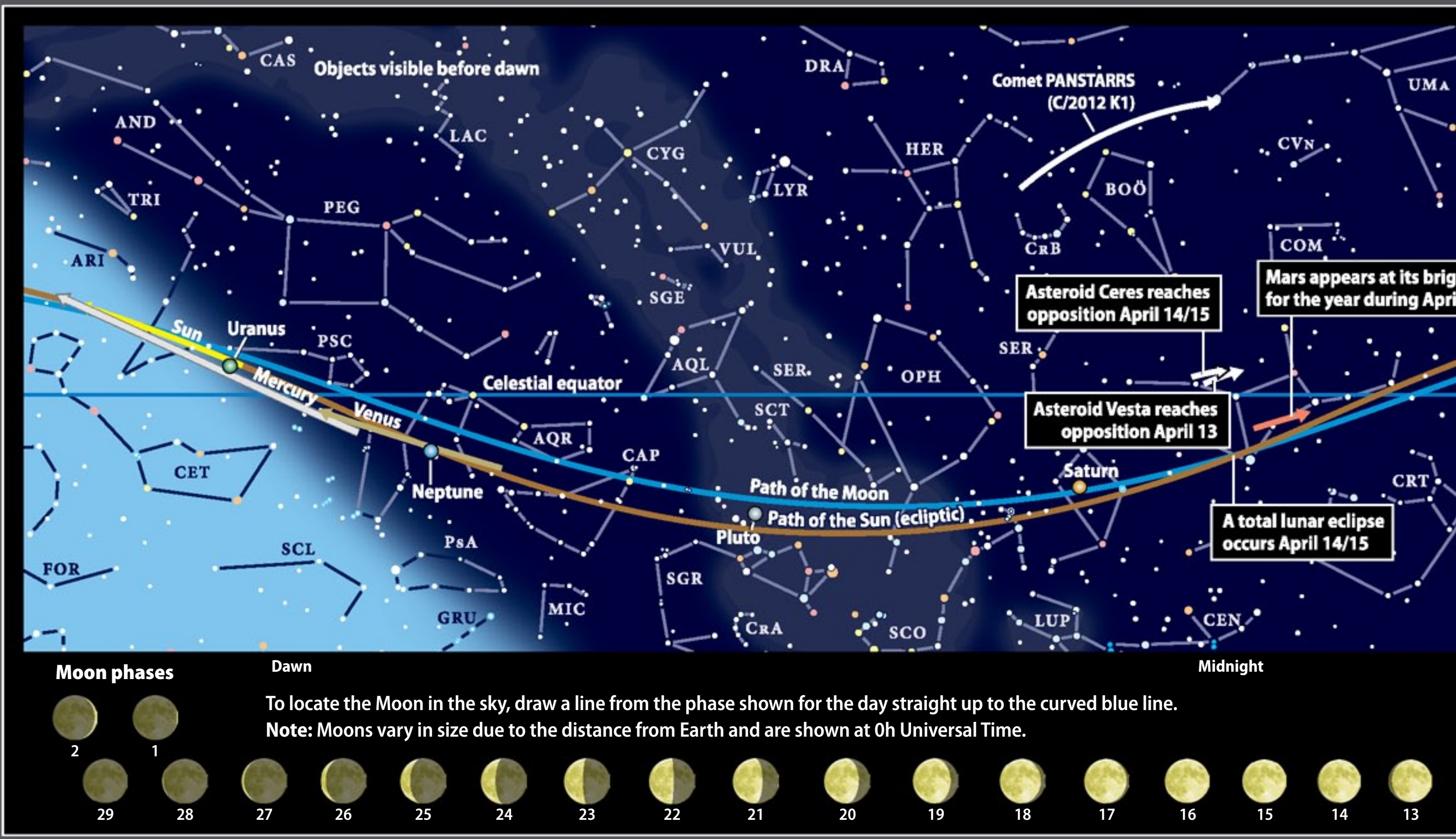
27 The Moon passes 2° north of Uranus, 7 A.M. EDT

29 New Moon occurs at 2:14 A.M. EDT; annular solar eclipse

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

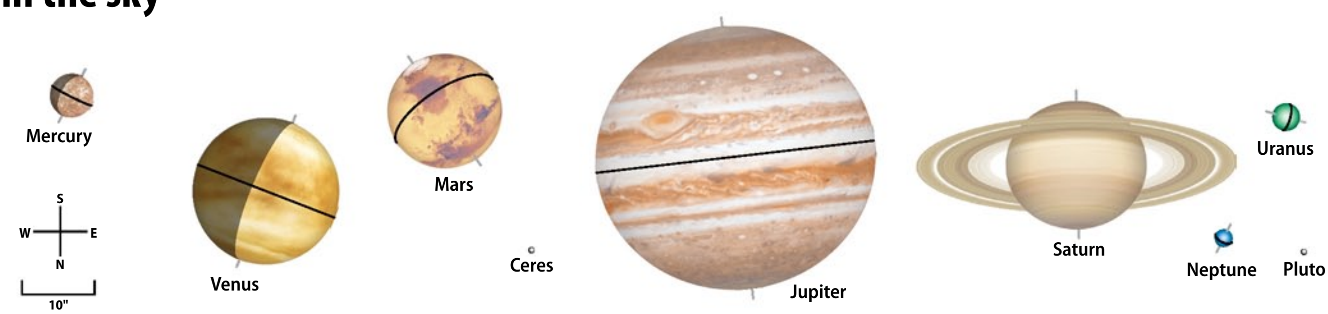
PATH OF THE PLANETS

The planets in April 2014



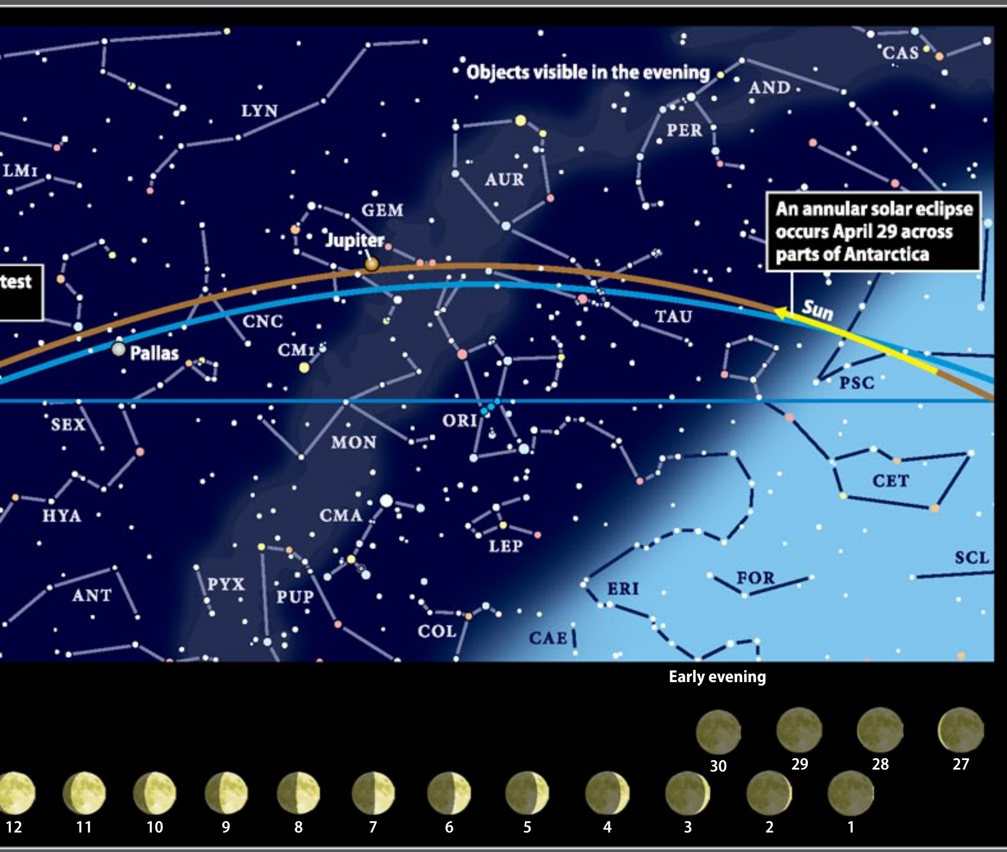
The planets in the sky

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets for the dates in the data table at bottom. South is at the top to match the view through a telescope.



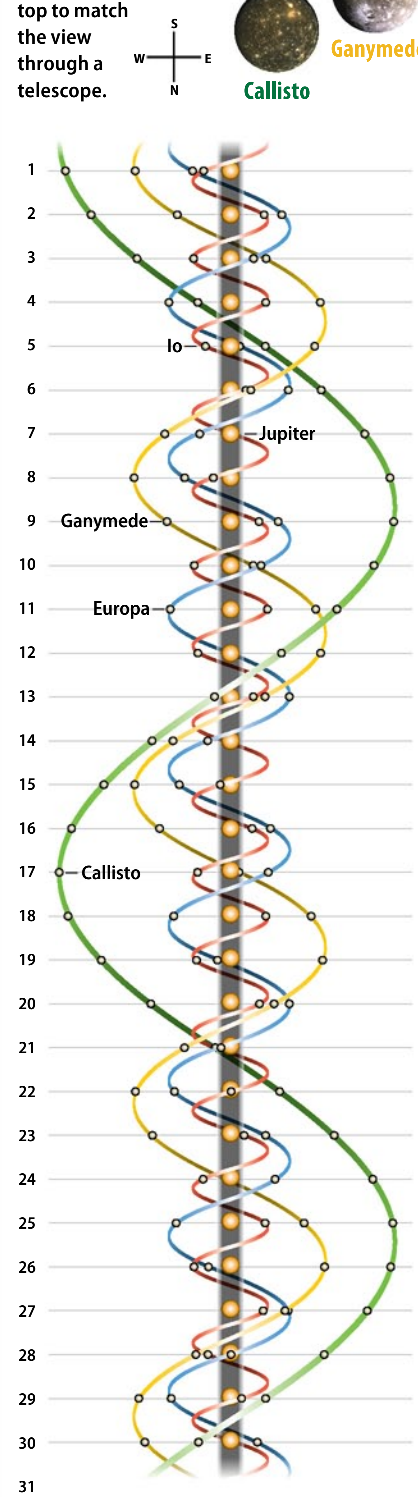
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	April 1	April 15	April 15	April 15	April 15	April 15	April 15	April 15	April 15
Magnitude	–0.2	–4.3	–1.4	7.0	–2.1	0.2	5.9	7.9	14.1
Angular size	5.8"	19.4"	15.2"	0.8"	36.9"	18.5"	3.4"	2.2"	0.1"
Illumination	77%	60%	100%	100%	99%	100%	100%	100%	100%
Distance (AU) from Earth	1.166	0.859	0.618	1.643	5.348	8.999	21.008	30.636	32.421
Distance (AU) from Sun	0.447	0.726	1.616	2.628	5.230	9.903	20.027	29.976	32.633
Right ascension (2000.0)	23h23.2m	22h45.2m	13h03.9m	13h53.2m	6h55.1m	15h19.5m	0h48.8m	22h34.3m	18h57.0m
Declination (2000.0)	–6°34'	–8°11'	–4°21'	3°26'	23°07'	–15°47'	4°32'	–9°44'	–20°06'

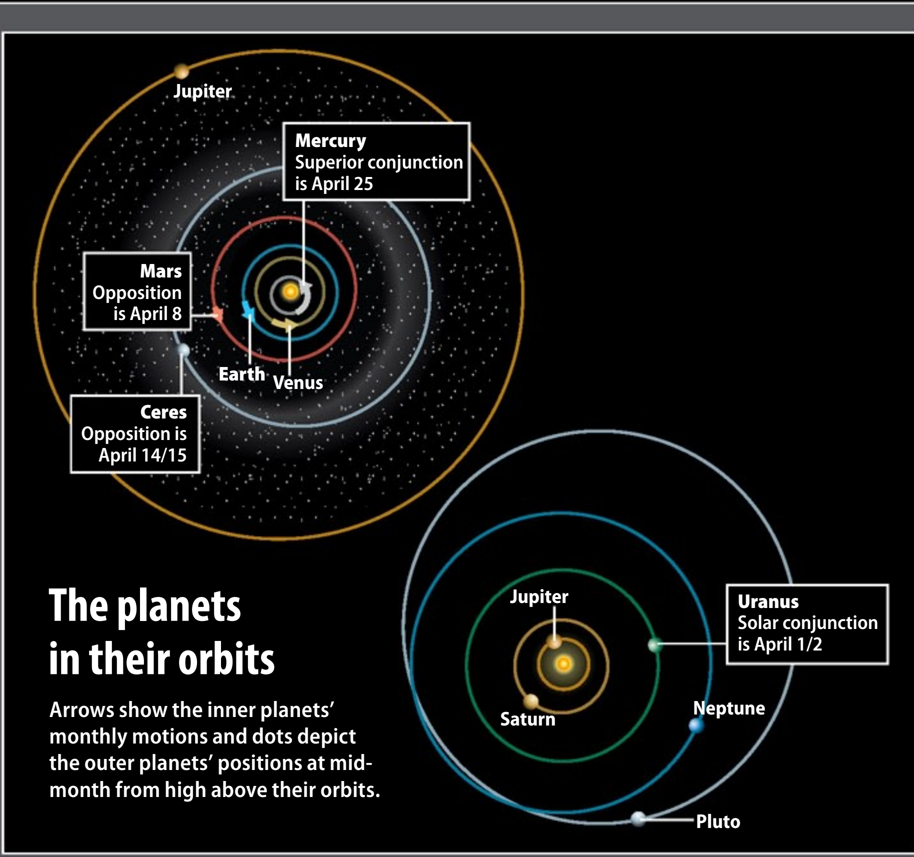
This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.



Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.





The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Mars (southeast)	Mars (south)	Mercury (east)
Jupiter (west)	Jupiter (west)	Venus (east)
	Saturn (southeast)	Mars (west)
		Saturn (southwest)
		Uranus (east)
		Neptune (east)

move backward (from west to east) if you observe at the same time each night. During a full month, the planet's entire face shows up at one time or another.

Let's begin at midnight EDT the night of April 1/2. The hemisphere facing Earth consists mostly of bland desert regions with few dark features. The most prominent dark marking is Mare Cimmerium in the south, while the plains of Utopia form a dark band around the north polar region.

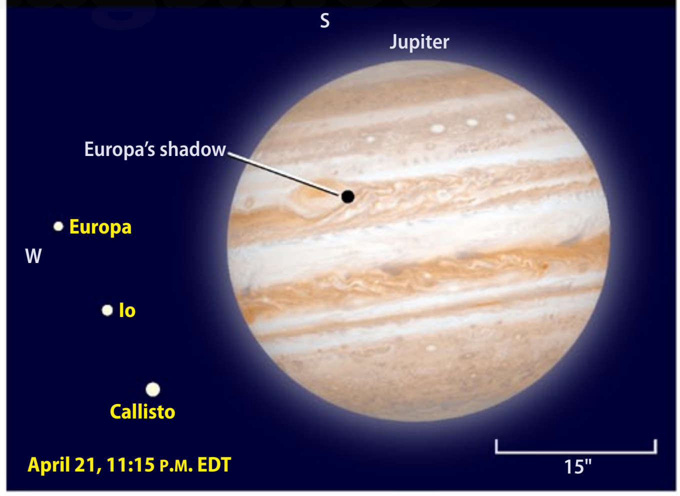
At opposition on April 8/9, the martian deserts take center stage. You won't see many dark features until around April 15, when the midnight hour reveals the dark patches Mare Erythraeum and Aurorae Sinus south of the equator and Acidalia Planitia toward the north polar region. The late evening of April 21 brings Acidalia Planitia near the martian central meridian, the line of longitude that runs from pole to pole and passes through the center of the planet's disk. That same night, the fine linear dark feature Sinus Sabaeus appears just east of the central meridian.

April's final week features late-evening views of Mars' most prominent dark area, Syrtis Major. This wedge-shaped marking appears near the planet's eastern limb by midnight EDT on April 25/26. It backs up each succeeding night until it lies on the central meridian April 30.

It's easy to see why Mars grabs most of the attention this month, but another stunning planet gives it a run for its money. **Saturn** brightens from magnitude 0.3 to 0.1 during April, which makes it approximately 10 times brighter than any of the background stars in the constellation Libra the Balance. The planet rises around 10:30 P.M. local daylight time in early April and two hours earlier (during twilight) by month's end.

Saturn will reach opposition in May, and its stunning

Jupiter's moons form a rare vertical line



Although Jupiter's moons often line up parallel to the planet's atmospheric bands, they form a perpendicular line April 21. ASTRONOMY: ROEN KELLY

COMETSEARCH

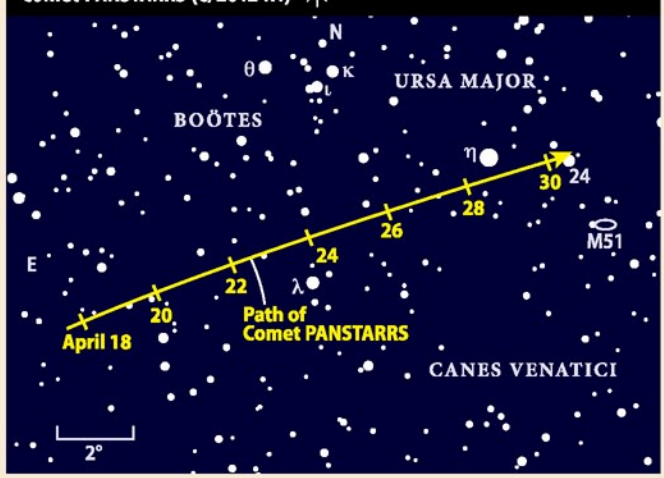
A comet squeezes the Big Dipper's handle

Comet PANSTARRS (C/2012 K1) should show up nicely this month through a 3-inch telescope under a country sky. Glowing around 9th magnitude and with a predicted diameter of several arcminutes, this visitor from the solar system's icy depths likely will appear similar in brightness and size to the brighter elliptical galaxies in the Messier catalog. But the comet's short fan-shaped tail will make it look noticeably different from a galactic fuzzball. Of course, you might find the comet in a larger scope while peering through a city's light dome, but only if you want the challenge.

Do you get a feeling of déjà vu when you see the name "PANSTARRS"? Don't, this isn't the same comet that graced our sky a year ago. The prolific robotic telescope's family name gets attached to dozens of comets, so professional astronomers typically use its technical label, C/2012 K1, to avoid confusion.

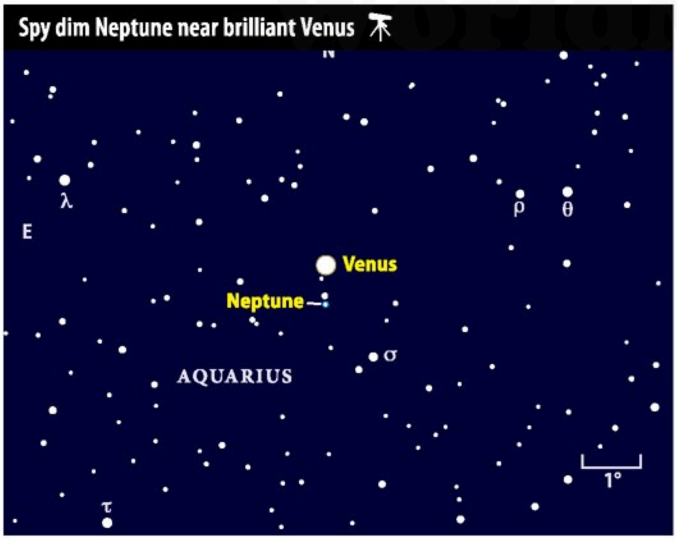
With the Full Moon lighting up the sky around midmonth, the best times to view the comet are in early and late April. Thankfully, it passes reasonably close to bright deep-sky objects at both times. As April opens, PANSTARRS lies in Corona Borealis, not far from the great globular star cluster M13 in Hercules. By month's end, the comet skims between Eta (η) Ursae Majoris, the star at the end of the Big Dipper's handle, and the Whirlpool Galaxy (M51) in Canes Venatici.

Comet PANSTARRS (C/2012 K1)



Comet PANSTARRS spends April's final days near the tip of the Big Dipper's handle, not far from the glorious Whirlpool Galaxy (M51). ASTRONOMY: ROEN KELLY

Once you track down PANSTARRS, increase your scope's magnification to 100x or more. You should see a bright dot, called the "false nucleus," near the glow's center. This thick shroud of dust hides the comet's true surface from view. The short tail sprouts almost due north, pointing away from the Sun.



Venus passes just north of Neptune on April 12, but you'll have to look carefully to see the distant planet's 8th-magnitude glow. *ASTRONOMY*: ROEN KELLY

appearance through a telescope during April nearly matches this upcoming peak. For the best views, wait until the planet climbs higher in the sky after midnight. In mid-April, Saturn's disk measures 18" across while the rings span 42" and tilt 22° to our line of sight. This steep angle provides a great vantage point for seeing the rings' structure.

As you marvel at Saturn's beauty, take a few minutes to track down the planet's brighter moons. Titan shines at 8th magnitude and shows up through any scope. You'll need a 4-inch instrument to spot Tethys, Dione, and Rhea, which all glow at 10th magnitude. Iapetus appears similarly bright when it lies farthest west of the planet (9' away) in mid-April. This two-faced moon dims as it moves away from greatest western elongation and its dark hemisphere turns more toward Earth.

As Mars and Saturn wheel into the western sky before dawn, **Venus** rises in the east. The brilliant planet pokes above the horizon about two hours before the Sun in early April and 20 minutes later by month's end. You won't have any trouble distinguishing Venus — at magnitude –4.3 in mid-April, it is the brightest point of light in the night sky. A telescope reveals slow changes in the planet's appearance. On April 1, Venus' disk spans 22" and the Sun illuminates just over half of it. By the 30th, it appears 17" across and two-thirds lit.

You can use the brightest planet as a guide to the dimmest April 12. That morning, Venus passes just 0.7° north of **Neptune**. Although the two appear along the same line of sight, Neptune lies 37 times farther from Earth and glows dimly at magnitude 7.9. Spying the distant planet through a telescope will be difficult, especially after twilight starts.

The solar system's other two planets deserve only brief mentions. **Mercury** lies deep in morning twilight in early April. From mid-northern latitudes on the 1st, it appears just 1° high a half-hour before sunrise. It passes behind the Sun from our perspective on the 25th. **Uranus** stands on the Sun's far side the night of April 1/2. Northern Hemisphere observers likely won't see the 6th-magnitude object even at month's end, when it rises during twilight.

The year's first **total lunar eclipse** occurs the night of April 14/15 for observers in the Americas west to eastern Australia. The Moon first dips into the darkest part of Earth's shadow at 1:58 A.M. EDT, with totality starting at 3:07 A.M. EDT and lasting 78 minutes. For complete details on viewing this event, see "Observe April's spectacular lunar eclipse" on p. 52.

Two weeks after the Moon crosses Earth's shadow, our planet enters the Moon's shadow. April 29's **annular solar eclipse** will leave a ring of sunlight visible around our satellite, but only for the hardiest of souls — you have to be in Antarctica to witness the peak. Residents of Australia can observe a partial eclipse. People along the country's southern coast will see the Moon block about 60 percent of the Sun in late afternoon while those in Tasmania will enjoy 70 percent coverage.

LOCATING**ASTEROIDS**

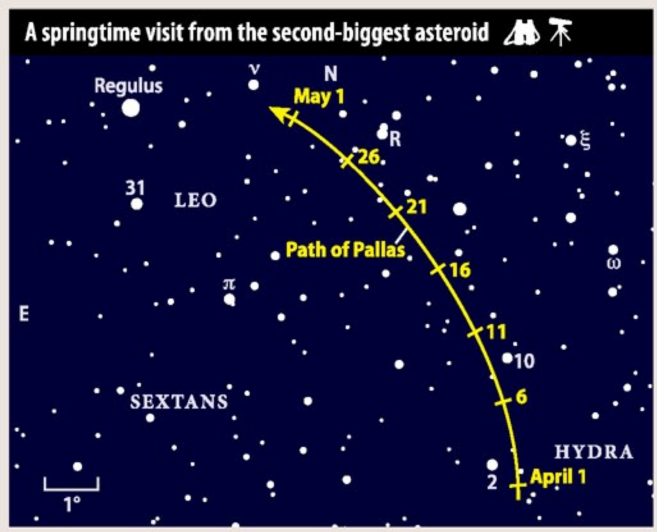
Pallas hears Leo the Lion's roar

German astronomer Heinrich Olbers discovered asteroid 2 Pallas in 1802. He noticed an object through his telescope that was not plotted on his star charts and that moved from one night to another. You can perform a similar feat this month, though you've got it a lot easier because you know exactly where and when to look.

As dusk settles into darkness, Pallas rides high in the south, not far from the luminary Regulus in Leo. The asteroid glows at 8th magnitude, bringing it within reach of binoculars under a dark sky or a 3-inch scope from the suburbs. Many of the background stars have a similar brightness, so make sure to orient the chart below to match your field of view.

With a diameter of about 325 miles, Pallas ranks second among the main-belt objects (in a virtual tie with 4 Vesta), but it is barely half the size of 1 Ceres. A close encounter with another object during the solar system's construction phases likely kicked Pallas into its highly inclined orbit.

As April closes, Pallas passes near R Leonis, a variable star that pulses over a 313-day cycle. R Leo is about four months past its peak, and its modestly deep orange color should make it a snap to identify.



Pallas glows at 8th magnitude as it crosses from Hydra into Leo during April, ending the month near the variable star R Leonis. *ASTRONOMY*: ROEN KELLY

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

The next search for Earth-like worlds

The Kepler spacecraft has found thousands of likely extrasolar planets. The next step is to characterize those worlds to learn if any of them harbor life. **by Liz Kruesi**

Using the Kepler space telescope, scientists have found about 100 possible planets orbiting in their stars' habitable zones, regions where liquid water could survive on planetary surfaces. Kepler-62f, illustrated here, is one such world. The next steps in exoplanet searches will bring scientists closer to finding worlds that host life. NASA/AMES/JPL-CALTECH (PLANET); NASA/KEPLER MISSION (KEPLER)

Just over 20 years ago, astronomers first detected signs of planets outside our solar system. Initially, they expected to find solar systems like ours, but they quickly realized that isn't how nature works. In fact, one of the first exoplanets discovered is about Jupiter's mass but circles its Sun-like star closer in than Mercury's orbit. Surveys over the past two decades have dug up similarly odd-looking planetary systems. But that doesn't mean scientists haven't found some similarities. They've discovered, for example, a world with a density nearly identical to Earth's and also confirmed nearly 200 planetary systems that hold multiple worlds.

NASA's Kepler spacecraft has participated greatly in the discoveries. After its launch in 2009, this observatory dug up thousands of likely worlds and showed that planets are common, before its mission ended recently due to equipment failure. Scientists think that out of Kepler's candidate planets, some 100 orbit in their stars' habitable zones. Within this distance range from the star, a planet would receive the right amount of stellar energy for liquid water to survive on the planetary surface. A recent study using data from the spacecraft found that one in five Sun-like stars likely has an Earth-sized world in its habitable zone.

While Kepler and its planet-hunting siblings have provided a wealth of tantalizing clues to potentially habitable worlds, there's still a lot to discover before astronomers can say they've found an Earth twin, the holy grail of exoplanet research. And, of course, they need to detect life's signature. What will it take to find it?

Tally thousands of worlds

Astronomers hunt planets by studying stars and looking for slight changes in their light that can signal one or more orbiting worlds. That's how they've found nearly all of the more than 1,070 confirmed exoplanets so far. In one detection method, for example, scientists analyze how light from a star shifts slightly due to an orbiting planet's gravitational force. As such a world moves away from Earth, its star's motion and speed are affected to keep the system balanced, shifting the star's detected radiation toward slightly bluer colors. As the planet begins to move toward Earth, it exerts force on its sun in the opposite direction, resulting in the star's radiation appearing redder.

Using this "radial velocity" detection method, scientists can measure those color changes and determine the mass and orbit of the planet that's pulling on its star. So far, astronomers have detected more than 540 worlds using this technique. The discovered planets tend to be massive and near their host stars — the type of worlds that contribute the greatest amount of gravitational pull. For the first decade of exoplanet discoveries, the radial velocity technique bagged nearly all the worlds.

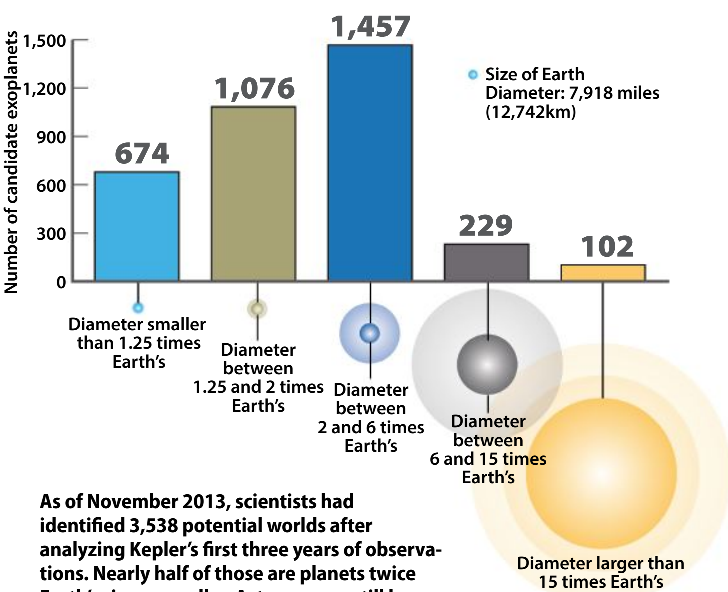
But that changed in the mid-2000s when scientists began employing the transit method more often. If a telescope sees a slight decrease in the amount of light from a star, it could result from a planet passing in front of, or transiting, that star from the telescope's point of view. The amount of light that the world blocks depends on its diameter (a bigger planet obscures more light than a smaller one that orbits at the same distance from its star).

Liz Kruesi *is an associate editor of* Astronomy. *The search for exoplanets has fascinated her since high school, when the first worlds outside the solar system were just being discovered.*

CHET BEALS/MIT LINCOLN LAB

The Transiting Exoplanet Survey Satellite, scheduled for a fall 2017 launch, will look for planets orbiting stars within a few hundred light-years of Earth.

Planet demographics



As of November 2013, scientists had identified 3,538 potential worlds after analyzing Kepler's first three years of observations. Nearly half of those are planets twice Earth's size or smaller. Astronomers still have a lot of data to analyze; they expect to uncover many more worlds. *ASTRONOMY*: ROEN KELLY, AFTER NASA

In 2006, the French National Space Agency launched the first space observatory to hunt exoplanets this way — the Convection Rotation and planetary Transits (CoRoT) mission. CoRoT observed several thousand stars in each of four different fields and found some 30 planets (plus another hundred candidates).

In 2009, NASA launched Kepler — CoRoT's "big brother." This telescope was capable of providing astronomers with the statistics of how many Earth-sized planets orbit Sun-like stars. For nearly four years, Kepler stared at more than 150,000 suns in the same patch of sky, looking for tiny changes in brightness. As of late January, astronomers have identified more than 3,500 candidate worlds and confirmed 242 in just about half of the Kepler data. The craft's observations showed both scientists and the public that worlds around other stars are common and which sizes of planets are more widespread.

The Kepler team was forced to end the mission in the summer of 2013 after two of the craft's four stabilizing wheels went kaput. With just two wheels left, the observatory could not remain fixed on the same patch of sky. Scientists are a crafty bunch, however, and in December 2013, they announced a possible way to rejuvenate the project (see "Kepler's second chance" on p. 48).

Even if the mission doesn't resume, researchers will find more worlds in the telescope's unanalyzed data. The Kepler team "believes there are hundreds of small planets, many of them in or near the habitable zones of their stars, that have not yet been found in the data," says Principal Investigator Bill Borucki of NASA's Ames Research Center in Moffett Field, California. That will hopefully keep scientists busy until the next large-scale exoplanet searches begin.

Look for the neighbors

No other spacecraft can currently find worlds at the pace set by Kepler. But astronomers have two space observatories scheduled for 2017 launches to push forward the search — one from the European Space Agency (ESA) and the other from NASA.

ESA's CHaracterizing ExOPlanet Satellite (CHEOPS) is a small-scale transit mission. CHEOPS will observe 50 stars, one at a time, that scientists know host super-Earth-sized to Neptune-sized planets (those between 1.25 and six times Earth's diameter) and look for other worlds. Astronomers also will scour the stars' light to tease out the masses of those other planets. By combining the known mass information with the newly observed diameter data obtained from the transit observations, researchers will be able to calculate the density of those worlds and thus theorize what they're composed of.

NASA's Transiting Exoplanet Survey Satellite (TESS) will operate similarly to Kepler and will look for minute brightness changes in a star's light. However, whereas Kepler focused on a small section of the sky — about 100 square degrees — for years, TESS will "basically paint the sky in stripes that go from the ecliptic up to the poles," says Principal Investigator George Ricker of the Massachusetts Institute of Technology (MIT). "We dwell on each stripe for about a month, and then we step to the adjacent stripe." Over its two-year primary mission, TESS will monitor nearly the entire sky — about 40,000 square degrees.

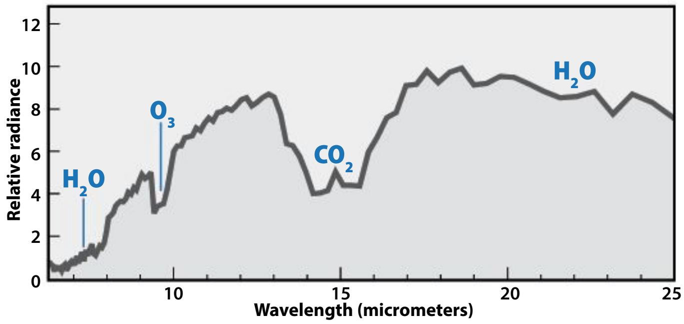
> **To search for life, astronomers look for gases that "don't belong" according to chemistry and physics models.**

More specifically, the satellite will study the 500,000 brightest and nearest stars, those within a few hundred light-years, in hopes of finding all candidate worlds in our Sun's neighborhood. "We want planets that are close to Earth," says Sara Seager of MIT, "because the closer planet-star systems are, the brighter they are. And the brighter they are, the more photons we can get. And the more photons we can get, the more information we can get." Researchers can then use that data to learn about a world's traits, like atmosphere and weather.

Scientists want to find worlds that orbit their stars within the habitable zone. In our solar system, Earth sits within this orbit, while Venus doesn't. (Mars actually does too, which is a major reason why scientists continue to study it with hopes of finding signs of past life. They have confirmed that the Red Planet once had flowing water.)

A smaller and cooler star's habitable zone, like that of a red dwarf, lies much closer to that sun than that of a hotter star's. Planets nearer to their stars move faster and orbit in less time than those that lie farther away. For example, in our solar system, Mercury moves at about 107,000 mph (172,000 km/h) and completes a full rotation around the Sun in 88 days; Saturn travels with an average speed of roughly 22,000 mph (35,400 km/h) and takes 29.5 years to orbit the

Earth's biosignatures



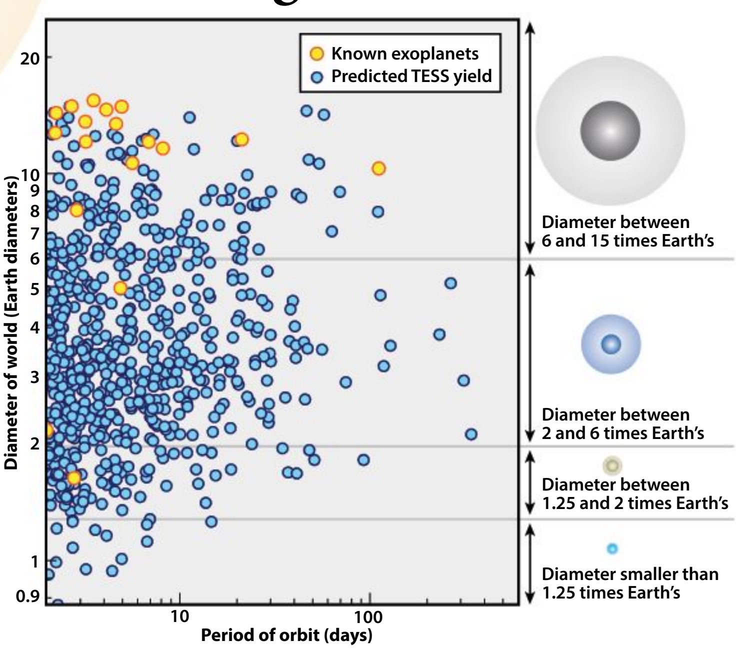
When the Mars Global Surveyor traveled to the Red Planet, one of its instruments observed Earth. This spectrometer captured data of specific energy ranges that our planet's atmosphere absorbed from the Sun, which tells scientists the composition of Earth's atmosphere — like water, ozone, and carbon dioxide. Astronomers plan to analyze atmospheres of exoplanets the same way with the James Webb Space Telescope. *ASTRONOMY*: ROEN KELLY, AFTER SARA SEAGER

Sun. Scientists need to detect at least three dips in light to categorize the signal as something orbiting a star, so if they want to detect possible life-hosting worlds in less time, they study cooler stars. TESS' "sweet spot," says Seager, is big Earths orbiting small stars.

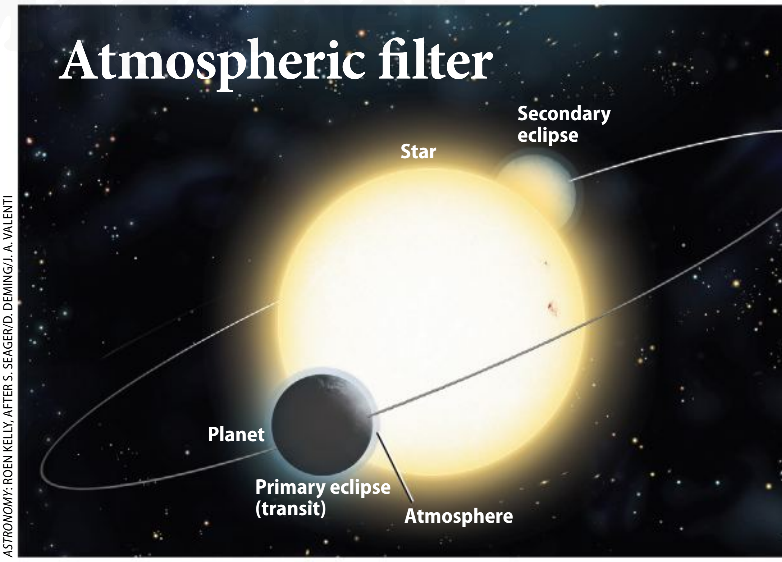
This type of star is also the most common in the galaxy. (In fact, scientists have found 248 red dwarfs within 32 light-years of our solar system, compared to just 20 like our Sun and 10 even hotter and larger stars.) Astronomers expect TESS to find hundreds of Earth analogs and super-Earths — worlds between one and about 10 times the mass of our planet. But this mission will tell them little about those worlds themselves.

Using TESS data, scientists will identify the best objects to analyze further with additional projects that could uncover the

In the neighborhood



Astronomers estimate that the Transiting Exoplanet Survey Satellite (TESS) will find some 300 super-Earth-sized and Earth-sized worlds. The telescope will focus on stars that are nearby and cooler than the Sun, which have habitable zones closer in than our star does. *ASTRONOMY*: ROEN KELLY, AFTER GEORGE RICKER



ASTRONOMY: ROEN KELLY, AFTER S. SEAGER/D. DEMING/J. A. VALENTI

When a planet crosses in front of its star (in a transit or primary eclipse), scientists can measure the size of the world and see how its atmosphere affects its sun's radiation. When the planet passes behind its star (in a secondary eclipse), researchers can learn what portion of the detected light from the transit is actually from the star and how much is from the world.

planets' makeups. Those future projects include NASA's next big space observatory — the James Webb Space Telescope, scheduled to launch in 2018.

Sniff the air

While the solid body of a planet that crosses in front of its star blocks light, its surrounding atmosphere — if it has one — alters that light. When the planet passes behind the star (an event called a secondary eclipse), the overall amount of light detected from the system will drop. Using that change, scientists can figure out how much radiation comes from the star alone and how much comes from the planet. Then they can study the world's spectrum, which tells them what materials make up its atmosphere.

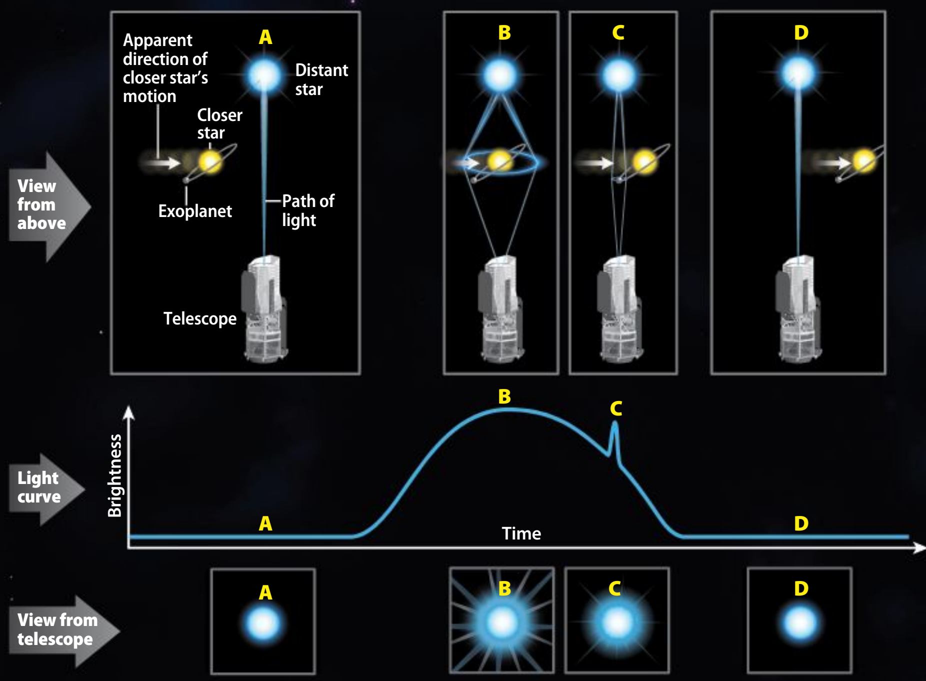
Different materials in the atmosphere absorb radiation at certain wavelengths, so the spectrum will show these wavelengths as "missing." Scientists know what colors correspond to different gases from laboratory experiments on Earth. Ozone (O_3), for example, absorbs light at 9.6 micrometers; carbon dioxide (CO_2) absorbs radiation at 15 micrometers.

To search for life, astronomers look for gases that "don't belong" according to chemistry and physics models. Oxygen, for example, doesn't live long, so if there are large amounts of it, something must be replenishing it — like life. But it's not just oxygen or ozone that scientists look for. "On Earth, there's untold number of gases produced by life, probably thousands," says Seager. "The reality is we're just going to have to keep an open mind and look for gases that simply don't belong by many orders of magnitude."

"TESS will find good candidates for sniffing the atmospheres of lower-mass planets around lower-mass stars," says Scott Gaudi of Ohio State University in Columbus. Astronomers will then study those suns with the Webb telescope. "That's our next big tool to characterizing and learning about the personalities of these planets."

Each transit lasts a few dozen minutes to a couple hours, and Webb will need to detect at least 10 of them — and likely a few times that many. Seager compares the length of observing needed for one exoplanet to the Hubble Deep Field, a focused 1-million-second-long image. Because Webb is a large-scale mission that will be used for a

A trick of gravity



In gravitational lensing, a nearby star's gravity acts as a lens that warps and brightens the light from a background star. If the nearby star also has an orbiting planet that crosses in the line of sight, it too will increase the brightness of the background star. Astronomers have discovered a handful of stars using this technique, but they expect to find many more. *ASTRONOMY*: ROEN KELLY, AFTER LAS CUMBRES OBSERVATORY; NASA (WFIRST)

KEPLER'S SECOND CHANCE

After the Kepler spacecraft's second stabilizing wheel died in May 2013, astronomers thought the planet-hunting mission was over. (The first wheel stopped working in July 2012.) The probe needed at least three of its four gyroscope wheels to stabilize it in three dimensions and detect the tiny 30-parts-per-million (ppm) brightness fluctuations that result from small transiting worlds. Its telescope was still operable, though, so scientists and engineers figured out a way to continue using the hardware.

If they position Kepler so that it lies parallel to its orbit around the Sun and has our star at its back, the Sun's radiation pressure can maintain balance in one plane. Then, the two remaining working wheels can ensure that the spacecraft points in a particular direction. Scientists will reposition the craft before sunlight enters the telescope — this will range from 40 to 85 days depending on the field of view.

Scientists have dubbed this new proposed mission "K2." It won't monitor the same stars that Kepler did, but it will be able to see different fields and thus provide information about planet demographics in other regions. K2 could detect signals only as small as about 300 ppm, so it would be less sensitive.

The mission team hopes to demonstrate how the reworked stabilization performs over about 80 days in March through May. — *L. K.*

variety of astrophysics topics, scientists will need to limit Webb's time spent on exoplanet research and pick just a few dozen worlds.

The Exoplanet Characterization Observatory (EChO) is a candidate ESA mission that also will study exoworld atmospheres. It's a much smaller-scale satellite than Webb — about 1 meter wide compared to 6.5 meters — but EChO would be devoted to researching the chemical composition, weather, and structure of atmospheres of about 100 exoplanets. If approved, the spacecraft would launch in 2024.

Atmospheric studies from both Webb and EChO would tell scientists about the planets' surface temperatures, cloud cover, and general weather patterns. And, of course, they would search for the signatures of life.

The importance of chance

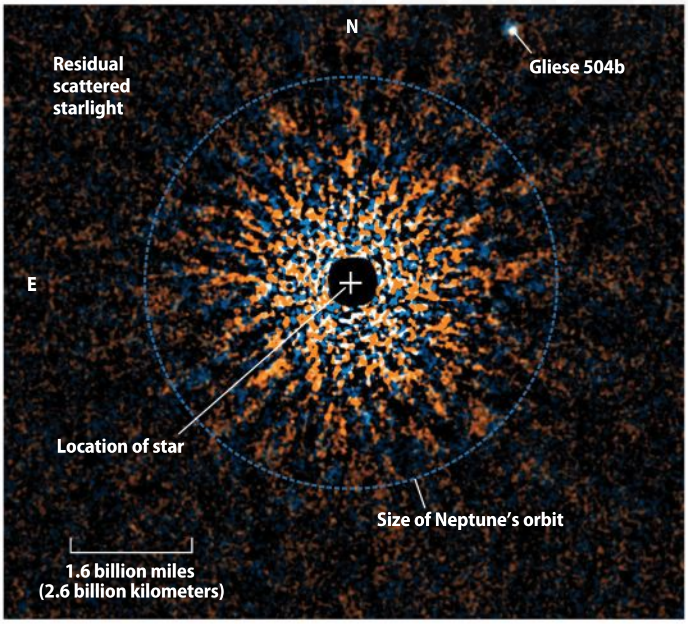
Transit and radial velocity searches, while the two most common exoplanet-hunting techniques, are certainly not the only ones. Another method, called microlensing, uses a trick of gravity. Any body with mass bends space-time, and the light from a background object will follow that warping. If a star crosses along the line of sight between Earth and a distant sun, the "gravity of the foreground star bends the light of the background star and focuses it," says Gaudi. "The background star gets first brighter and then fainter as the alignment gets better and then worse as the star moves along its merry way." On average, it takes about 100,000 years of staring at a single star to see this happen once.

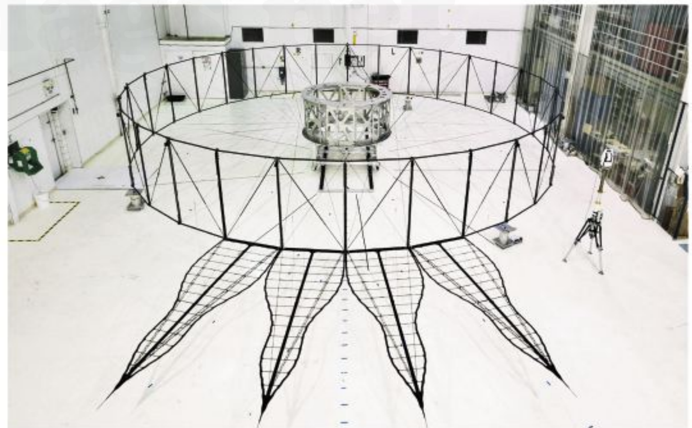
Scientists won't just find the planets; they also would be able to study the light spectrum of an imaged world directly.

If that foreground star happens to have a planet, it could also cross the line of sight and create a similar magnification effect, but on a smaller scale. "Microlensing is a powerful technique because you can get very large signals for very small planets," says Gaudi. "You can get like tens-of-percent signals from Mars-mass planets. In principle, you can find planets down to the mass a few times that of Moon." He compares the reasoning behind the intense brightening to an effect seen in a glass of water on a sunny day: "Occasionally, you get these super-bright spots where the sunlight is being focused by this water. That water is taking the light from the Sun that's coming from many different directions and focusing it all into one direction."

Astronomers have used microlensing to find evidence of a few worlds unattached to any star, and they hope to use sky surveys to monitor larger swaths of sky — and thus millions of stars — looking for more planets with this method. The proposed Wide Field Infrared Space Telescope (WFIRST) is one such project. If NASA approves it, WFIRST will monitor hundreds of millions of stars more or less continuously for 170 days out of the year. Astronomers will use the collected data to search for exoplanets as well as study galaxy structure across cosmic time, look for bright exploding stars, and try to answer some of the biggest questions about how the universe has evolved.

WFIRST topped the National Academy of Sciences Decadal Survey for Astronomy as the priority for a large space mission, and NASA is putting considerable developmental effort into the project.





▲ **Researchers are working on a prototype starshade. This 34-meter-wide instrument would block the light from a distant sun, allowing the orbiting planet's reflected light — about 10 billionth the brightness — to be visible.** JPL

◄ **Current technology limits the size and brightness of exoplanets that scientists can directly image. Gliese 504b is the lowest-mass world so far photographed around another star. It weighs about 4 Jupiter masses and orbits its Sun-like star from about 44 times the Earth-Sun distance.** NASA'S GSFC/NOAJ

If Webb launches and begins operations on time, WFIRST will likely be NASA's next big mission, slated for a 2023 launch.

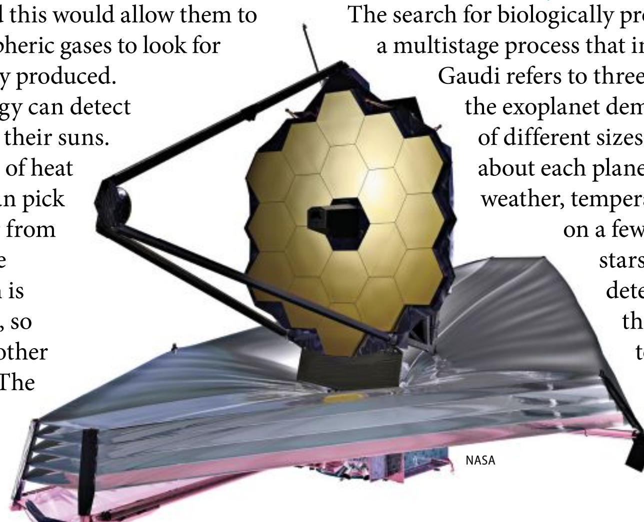
What is a picture worth?

The methods described so far in this article all use indirect ways to find and study worlds around other stars, but "eventually what we want to do is direct imaging," says Gaudi. Scientists won't just find the planets; they also would be able to study the light spectrum of an imaged world directly instead of just seeing its star's radiation filtered through an atmosphere. And this would allow them to learn more about the planet's atmospheric gases to look for compounds that could be biologically produced.

Current direct-imaging technology can detect only young worlds orbiting far from their suns. Newly formed planets still emit a lot of heat from their creation, and scientists can pick out of the bright starlight planets far from their stars (distances similar to those between Uranus and the Sun). Earth is 10 billion times fainter than the Sun, so picking out a similar signal around other stars would be extremely difficult. "The classic analogy is like trying to resolve a firefly next to a spotlight at the distance of New York from Los Angeles," says Gaudi.

In November 2013, the newest direct-imaging instrument saw first light. The Gemini Planet Finder, attached to the 8-meter Gemini South Telescope in Chile, will observe infrared radiation from about 600 large young exoplanets over two years. Astronomers expect these worlds to orbit their stars from distances between five and 40 times Earth's separation from the Sun.

Some scientists are working on a way to include on WFIRST an instrument called a coronagraph to block a star's light and look for its orbiting planets. Seager and colleagues are investigating something similar: a starshade and telescope system. The two parts would launch together. Once in space, the starshade would unfold and the two instruments would separate by tens of kilometers. To work properly to block the bright star from view, they would need to be aligned within a meter of the line of sight to a chosen observational target. Such a system is still many years away, but Seager's team is beginning to test the technology with a prototype starshade.



NASA's James Webb Space Telescope is an infrared observatory set to launch in 2018. Its 6.5-meter-wide mirror will provide observations of the compositions of a few dozen exoplanets' atmospheres.

It takes many steps

The search for biologically produced gases on Earth-like worlds is a multistage process that involves many avenues of exploration. Gaudi refers to three distinct steps: First, determine what the exoplanet demographics are (how common worlds of different sizes and orbits are). Next, learn indirectly about each planet's characteristics, like mass, radius, weather, temperature, and atmosphere. Third, focus on a few Earth-like worlds around nearby stars and study those in greater detail to determine if they do host life. "All of these are necessary steps that we have to take, but they're part of the overall goal of basically trying to find a 'pale blue dot' and characterize its atmosphere," says Gaudi.

Each phase to get to that objective tells scientists a great deal about the worlds around us. It also teaches them how the solar system formed and evolved. So far, they've found none that look just like our home system — but that does not necessarily mean it is unique, rather that the current tools can't yet detect and characterize other systems in enough detail.

Only after analyzing and cataloging many similar systems can astronomers determine how many worlds just like ours, and inhabited by living beings, exist. The next few decades hold immense promise for answering the age-old question of whether we're alone.

VISIT **www.Astronomy.com/toc** TO VIEW A GALLERY OF DIRECTLY IMAGED EXOPLANETS.

A MATTER OF PERSPECTIVE

Q: WHY DO THE CONSTELLATIONS AND THE MOON APPEAR UPSIDE DOWN FROM THE SOUTHERN HEMISPHERE?

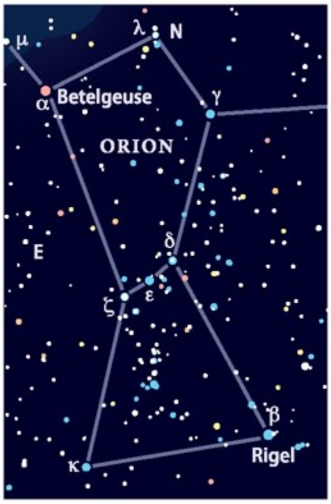
***Paul Kersey,** Phillipsburg, New Jersey*

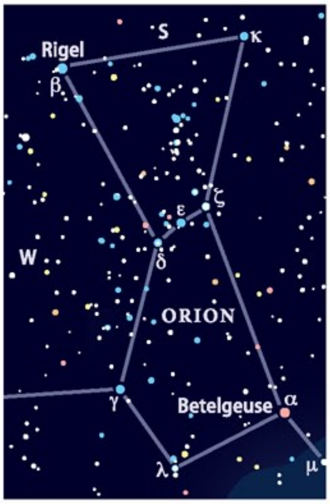
A: From the Southern Hemisphere, any object or constellation that lies near the celestial equator (the imaginary line that divides the northern and southern halves of the sky) would appear both upside down and reversed left to right compared to a northern perspective.

Let's use the constellation Orion as an example. Copper-hued Betelgeuse (Alpha [α] Orionis) lies at the northeastern corner of the Hunter's torso, while blue-white Rigel (Beta [β] Orionis) marks his southwestern foot. From the Northern Hemisphere, observers have to look toward the south to see Orion, and therefore the southern part of the constellation appears closer to the horizon. And when you face south, east is to your left. So, observers see Betelgeuse at the upper left of Orion and Rigel at the lower right.

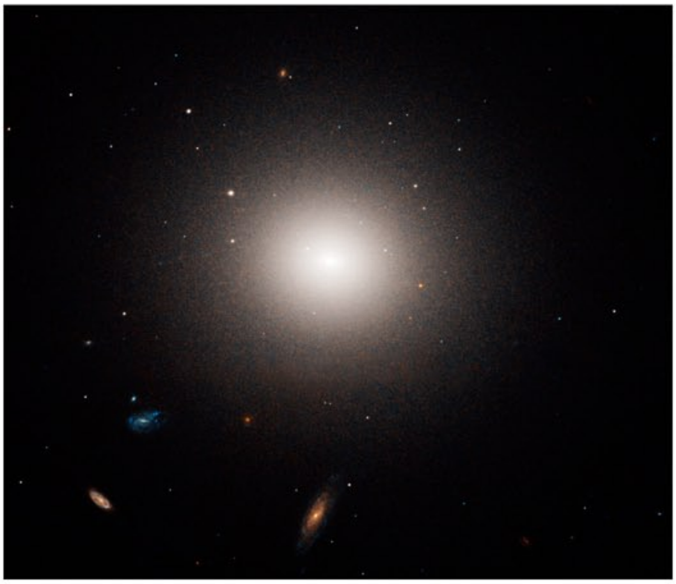
From the Southern Hemisphere, however, Orion appears in the north, so it's the northern part of the constellation that lies closest to the horizon. And when you look north, east is to your right. So the Orion that skywatchers see from the Southern Hemisphere has Betelgeuse at the lower right and Rigel at the upper left. The same geometry holds true for the other constellations as well as for the Moon and planets.

Michael E. Bakich
Senior Editor





The constellation Orion the Hunter looks upside down and flipped right to left in the Southern Hemisphere (right) compared to the Northern Hemisphere. ASTRONOMY: RICHARD TALCOTT AND ROEN KELLY



Scientists typically consider elliptical galaxies, like NGC 4458 (shown), "red and dead" because they're composed of mostly old stars that glow red and aren't forming new suns. Spiral galaxies have pockets of gas still converting into stars, and thus astronomers consider them "living." ESA/NASA/E. PENG (PEKING UNIVERSITY, BEIJING)

Q: WE KNOW THAT STARS HAVE LIFE SPANS. IS THERE ANY EVIDENCE THAT GALAXIES ALSO HAVE FINITE PERIODS OF EXISTENCE?

Ray Grewe
San Francisco

A: The answer depends on what you mean by "existence." Astronomers frequently talk about stars being "born" and "dying"; what they really mean is "starting nuclear fusion" and "ending nuclear fusion." Fusing hydrogen into helium and helium into other, heavier chemical elements is what makes a star "alive." (By this definition, I guess I really haven't lived.) Of course, most stars leave behind fascinating corpses that will endure indefinitely — white dwarfs, neutron stars, or black holes. Whether you think of these remnant objects as stars is a matter of semantics.

Similarly, most astronomers (either consciously or unconsciously) think of galaxies as "living" if they are busy converting interstellar gas into stars and "dead" if no more stars are forming. The Milky Way is middle-aged in this sense. Its star formation rate has been declining for some 11 billion years, and a day will come when our galaxy forms its final star. At that point, after all the young, hot, blue stars quickly burn out, only faint dwarf stars and red giants — stars on their way to their individual "deaths" — will be left. That day is at least 10 billion years away.

There are already many galaxies in the universe that astronomers refer to as "red and dead." Some of these stopped forming stars billions of years ago. Assuming they don't get any infusions of fresh gas from intergalactic space, these galaxies (and eventually the Milky Way, too) will gradually redden and fade away, leaving a collection of stellar embers.

Robert Benjamin
University of Wisconsin-Whitewater

Q: ASTRONOMY AND ASTROPHYSICS RELY HEAVILY ON COMPUTER MODELING, BUT BEING NEITHER A PHYSICIST NOR COMPUTER SCIENTIST, I CANNOT RELATE TO THE TERM "COMPUTER MODEL." WHAT IS SUCH A MODEL, AND HOW DO SCIENTISTS BUILD ONE?

Melvyn Goldberg
Toronto

A: This is easiest to explain by an example. Suppose we launch a spacecraft from Earth and want to calculate its trajectory thereafter. Newton's laws of motion and gravitation govern the probe. These laws are mathematical formulas that take as input the current position of the spacecraft and return as output the rate at which its velocity (meaning both its speed and direction) changes in response to the gravity of the Sun, Earth, other planets, and any other objects with mass.

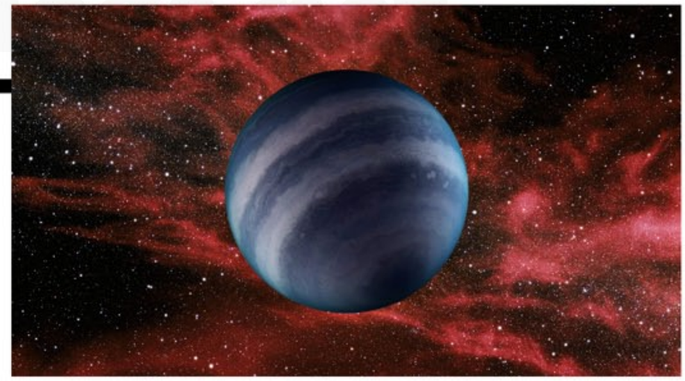
Thus, imagine the following procedure: (1) specify the spacecraft's starting position and velocity; (2) using Newton's laws and the current position, calculate the rate at which the probe's velocity is changing; (3) advance time by one second, during which the velocity changes by the amount calculated in step 2 and the position changes by an amount determined by the spacecraft's velocity; (4) using the new position and velocity, repeat steps 2 and 3 as many times as you want, and record the position versus time. A computer model is just a computer program that carries out these steps.

In general, a model is a computer program built on a set of known physical laws (in this case, Newton's laws), a starting configuration (the spacecraft's initial position and velocity), and some other ancillary data (the masses and locations of the Sun and the planets). The art of building a model is knowing which laws of physics are the relevant ones (can I use Newton's laws, or do I need to use relativity?), which ancillary data the problem requires (do I need to include all the planets, and what about asteroids?), and designing the details of the procedure (is one second the right time step, or should it be bigger or smaller?).

Mark Krumholz
University of California, Santa Cruz

Q: ASTRONOMERS RECENTLY DISCOVERED BROWN DWARFS OF ONLY A FEW HUNDRED DEGREES FAHRENHEIT, WHICH SEEMS ABOUT THE SAME TEMPERATURE AS SOME PLANETS. SO WHAT IS THE DIFFERENCE BETWEEN A BROWN DWARF AND A PLANET?

Ewell Schirmer
Plano, Texas



Astronomers recently found brown dwarfs with surface temperatures of a few hundred degrees Fahrenheit. They think these objects are around 15 times Jupiter's mass, but they may weigh even less — confusing the planet-brown dwarf separation even more. NASA/JPL-CALTECH

A: This is an excellent question, and it's one that even astronomers have a hard time agreeing on. There are three criteria that we consider when trying to distinguish among stars, giant planets, and brown dwarfs: how they formed, how massive they are, and what they look like.

All of the planets we study today — including the ones in our solar system — orbit a star. A planetary system's multiple worlds tend to orbit in the same direction and in nearly the same plane. These patterns indicate that planets form out of the circumstellar disks encircling young stars. (While we have observed such structures, scientists in the 18th century first conceived the idea.) On the other hand, we usually find brown dwarfs as isolated objects or in pairs, suggesting that they form like stars. This "formation" definition, however, depends on knowing how an object was made, which is not always clear. It also assumes we fully understand planet and star formation, but recent discoveries with the Spitzer, Kepler, and Herschel space telescopes indicate that we have much to learn about these processes.

Mass is another way to distinguish planets from brown dwarfs. We already separate brown dwarfs from stars at a mass of about 75 times that of Jupiter — below that, an object's core doesn't get hot enough for hydrogen to fuse (the key property of a star). An equivalent mass boundary between planets and brown dwarfs is the deuterium fusion limit, which occurs at about 14 times Jupiter's mass. Deuterium is an isotope of hydrogen that contains a proton and a neutron in its nucleus (a hydrogen nucleus contains just a proton). Deuterium is the easiest atom to fuse, so objects that cannot fuse deuterium cannot fuse *anything*, which sets a threshold for distinguishing the two classes of objects. Mass is also useful because we can directly measure it through, for example, the orbital motion of bodies in a binary system or microlensing observations (which utilize a trick of gravity).

Unfortunately, the mass definition occasionally conflicts with the formation definition. We've detected "free-floating non-fusors" in the Sigma (σ) Orionis cluster and the deuterium-burning "planet" CoRoT-3b. Plus, not all planets and brown dwarfs have masses that are easy to measure.

Distinguishing a planet from a brown dwarf based on its appearance is probably the most challenging approach. As you point out, we now know of brown dwarfs that have low atmospheric temperatures like giant planets and have the same atmospheric compositions (mostly hydrogen and helium), so the spectra we measure from brown dwarfs and planets are similar. We have increasing evidence that clouds in the atmospheres of brown dwarfs and giant planets might be different, but such research remains work in progress.

In practice, we use a combination of these characterizations to determine whether an object is a planet or a brown dwarf, and the International Astronomical Union has proposed a definition that combines the formation and mass criteria described above. But we still don't always agree. Last year, I conducted a survey of astronomers, students, and the public, asking them to classify 10 objects as planets, brown dwarfs, or something else. The group did not classify any of the objects unanimously as a planet or brown dwarf, and in some cases the vote was evenly split. Remarkably, many respondents chose the "something else" category for some of these objects.

Nature rarely conforms to our classification schemes. Reevaluating them in light of new discoveries helps us deepen our understanding of the universe.

Adam Burgasser
University of California, San Diego

Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Observe April's **spectacular lunar eclipse**

The first total eclipse of the Moon in more than two years will thrill North American observers. Here's what you need to know.

by Michael E. Bakich

Amateur astronomers have been counting the days — 857 of them, to be exact. That's how long it's been since the Sun, Earth, and the Moon (in that order) lined up; how long since the last time the entire Moon passed through the umbra, the darkest part of Earth's shadow; and how long since the last time anyone saw a total lunar eclipse. On April 15 — that's right, tax day — the wait will be over. As a bonus, it's merely the first of two total lunar eclipses in 2014. And you won't need any filter for either one.

Who will see it?

Readers will breathe a collective sigh of relief because observers throughout North and South America will have the prime views of this eclipse. Those in the western Pacific will miss the first half of the eclipse because it occurs before moonrise.

Likewise, most of Europe and Africa will experience moonset just as the eclipse begins. None of the eclipse will be visible from northern or eastern Europe, eastern Africa, the Middle East, or Central Asia. And, in case you're wondering, at mid-eclipse (which astronomers often call "the instant of greatest eclipse") the Moon lies overhead at a point in the South Pacific about 1,865 miles (3,000 kilometers) southwest of the Galapagos Islands.

Throughout the event, the Moon stands in front of the stars of the constellation Virgo the Maiden. Our satellite's apparent diameter then is 31', which is close to its average because this eclipse occurs nearly midway between apogee (when the Moon lies farthest from Earth) and perigee (when it's closest to Earth). This is also the first of four consecutive total lunar eclipses — all visible from somewhere in North America — that culminates in September 2015.

During the April 15 eclipse, the Moon's northern edge passes 1.7' south of the shadow's central axis. In contrast, its southern edge lies 9' from the southern edge of the umbra and 40' from the shadow's center. As a result, the Moon's northern half will look much darker than its southern half because it lies deeper in the umbra.

◄ Longtime *Astronomy* contributor Anthony Ayiomamitis captured the Moon's totality during the March 3/4, 2007, total lunar eclipse. Like this month's event, the Moon did not pass centrally through Earth's shadow. The result was that one side of our satellite's face appeared brighter than the other. ANTHONY AYIOMAMITIS

Because the Moon traverses a large range of the shadow's depths throughout totality, the appearance of its face will change significantly with time. And although the Moon doesn't pass through the center of Earth's shadow, you still will have plenty of time to enjoy the total phase, which lasts 78 minutes.

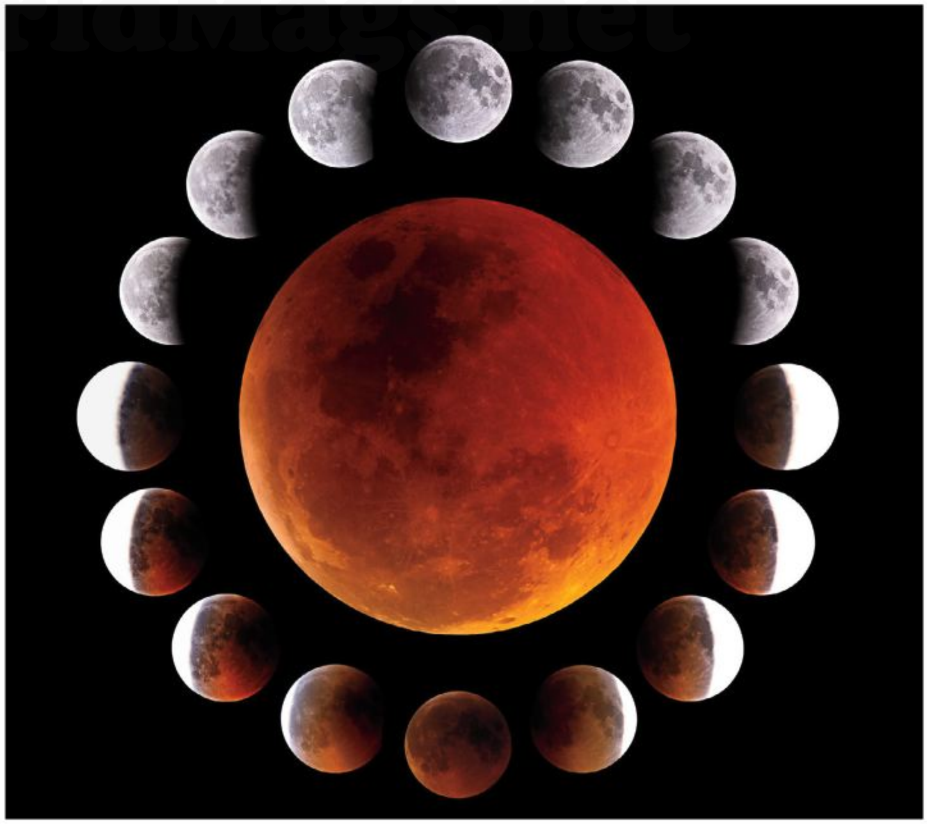
How dark is this eclipse?

The Moon's appearance during totality can vary greatly from one eclipse to the next. Obviously, the path the Moon takes through Earth's umbra — and how centered it is — has an effect. But so does our atmosphere because it contains water droplets and solid particles like dust and ash, which reduce the air's transparency.

A significant volcanic eruption before a lunar eclipse can darken the Moon's face considerably by pumping our atmosphere full of particles that halt light. Lots of clouds along the edge of our planet also can cut down the light.

But in addition to appearing dark, the Moon takes on a particular color during totality. This occurs because our air bends some of the Sun's rays into the shadow. It also scatters the shorter (bluer) wavelengths out of that light, reddening it and darkening the Moon's face.

You can estimate the darkness of any total lunar eclipse by using a five-point scale developed in 1921 by French astronomer André-Louis Danjon. To determine the luminosity (*L*) of the eclipse, you can use your naked eyes, binoculars, or a telescope. Be sure to make your estimate near the time of mid-totality.



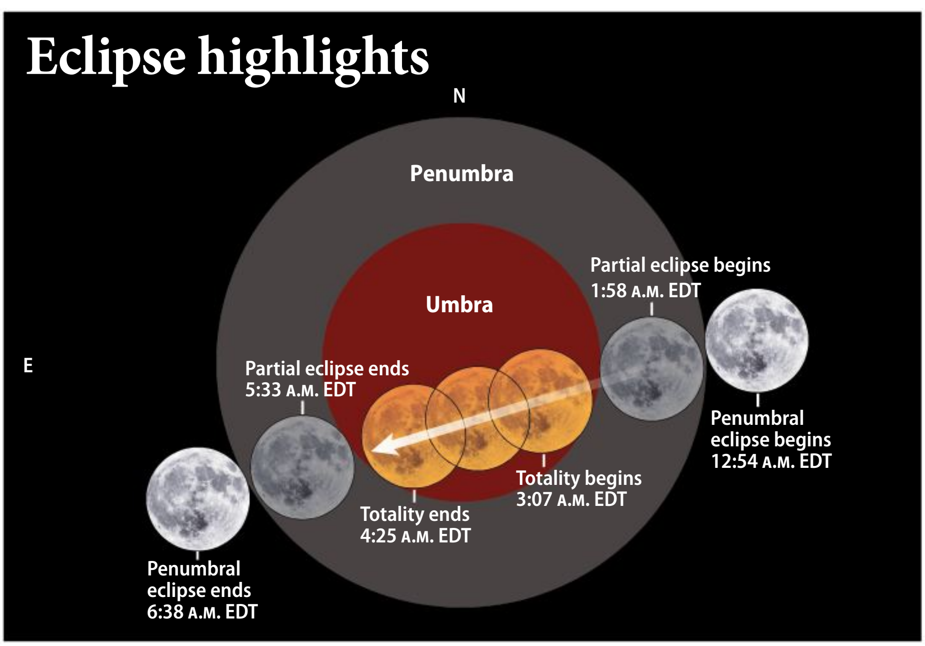
Jacques Deacon of Kathu, South Africa, took more than 300 images during the June 15, 2011, total lunar eclipse through a 9.25-inch Celestron Schmidt-Cassegrain telescope and a 50–500mm camera lens. His exposure times varied between 1⁄500 second and 10 seconds. JACQUES DEACON

In Danjon's system, *L* values stand for various luminosities, or the brightness the Moon's surface retains during totality. If L=0, it's a dark eclipse indeed; the Moon is almost invisible, especially at mid-totality. If L=1, the eclipse is dark with gray or brownish coloration and details are distinguishable only with difficulty. For L=2, the Moon appears deep-red or rust-colored; the central shadow is quite dark while the umbra's outer edge is relatively bright. L=3 indicates a brick-red Moon; the umbral shadow usually has a bright or yellow rim. And if L=4, the Moon looks bright copper-red or orange and the umbral shadow has a bright bluish rim.

In evaluating *L*, you should record both the instrument you used (if any) and the time. Also document any variations in the color and brightness of different parts of the shadow, as well as the sharpness of its edge. Pay attention to the visibility of lunar features within the umbra. Notes and sketches made during the eclipse will help you recall details later. Images are not as useful because cameras typically record more than the eye can see.

All 'round the Moon

During totality, the constellations of the Northern Hemisphere's spring surround the Moon. Magnitude 1.0 Spica (Alpha [α] Virginis) is the nearest bright star. At mid-totality, it lies just 1.5° west-southwest of



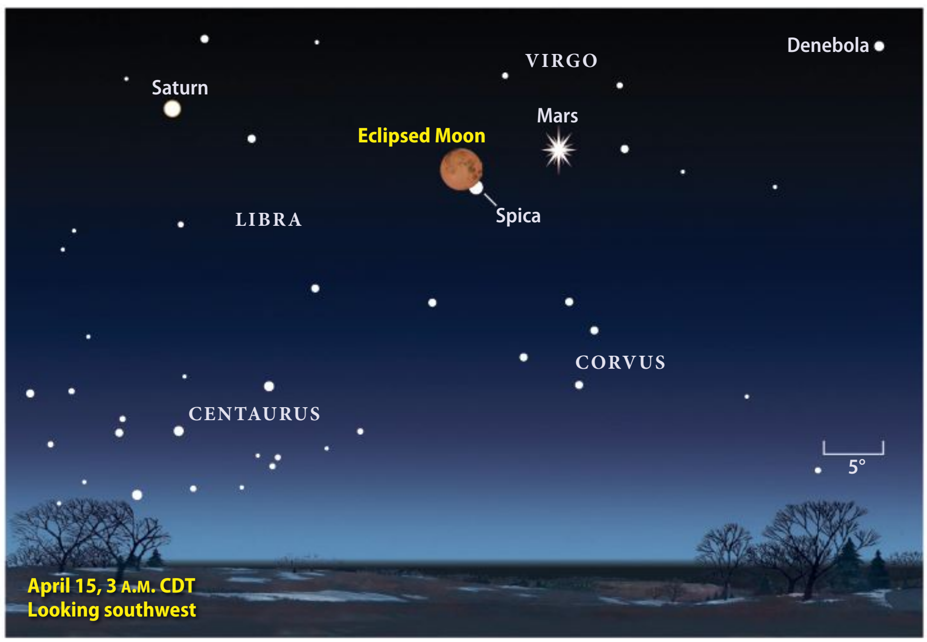
Here's a quick guide to the main events that will occur during the total lunar eclipse April 15. In addition to the times listed on the diagram, mid-eclipse occurs at 3:46 A.M. EDT. Note that in some time zones, events may occur before midnight, so if you live in one of those, the date will be April 14. *ASTRONOMY*: ROEN KELLY

This sequence of the partial lunar eclipse of June 4, 2012, certainly conveys the feeling of how the Moon moves through Earth's shadow. The photographer attached a DSLR to an 8-inch telescope, set the ISO at 800, and took — and then combined — a series of 1/600-second exposures. ROD POMMIER

THE UPCOMING ECLIPSE OF OCTOBER 8

The second lunar eclipse of 2014 is also total, and observers in North America can see at least part of it. The Moon then is in the constellation Pisces the Fish and appears 5.3 percent larger than it does during the April eclipse.

On October 8, and unlike the April 15 eclipse, the Moon's path takes it through the northern half of Earth's umbral shadow. Totality lasts 59 minutes. The partial phase begins at 5:15 P.M. EDT, totality starts at 6:25 P.M. EDT and ends at 7:24 P.M. EDT, and the partial phase ends at 8:34 P.M. EDT. And the farther west you are, the better. — *M. E. B.*



The totally eclipsed Moon on April 14/15 lies in the southern part of the constellation Virgo the Maiden, just 2° from that star pattern's brightest star, Spica (Alpha [α] Virginis), and 9° from Mars. The ringed planet Saturn also floats nearby, some 27° to the Moon's east-southeast. *ASTRONOMY*: ROEN KELLY

the eclipsed Moon. Spica's vivid blue color will contrast nicely with the crimson Moon — especially through binoculars.

Regarding other bright stars, Arcturus (Alpha Boötis) stands 32° to the Moon's north-northeast, and Antares (Alpha Scorpii) lies 45° to the east-southeast.

You also can spot Mars 9.4° northwest of the Moon. The Red Planet was at opposition April 8, so, at magnitude –1.4, it's shining as brightly as it will until 2016. It's also as large as it will be until then, so if you have a telescope set up for the eclipse, you'll have plenty of time to steal a glance at Mars, even during totality.

If you plan to observe the Red Planet during this event, it's a safe bet that you'll also be pointing your telescope at Saturn, especially if you are entertaining guests. The ringed planet lies 27° east-southeast of the Moon. Although not as bright as Mars, Saturn shines at magnitude 0.2, which makes it twice as bright as Spica.

A "totally" safe event

Sometimes, individuals and the media equate the words *eclipse* and *warning*. While that's valid for solar eclipses, a lunar eclipse poses no danger whatsoever to your eyes. All you're looking at is the Moon passing through a big shadow. Not only do you not need any filters, but you also can feel free to magnify the sight by using binoculars or a telescope.

So, invite your family and friends, host an eclipse viewing party, and revel in some cool, easy-to-understand science. Lots of astronomy clubs and science centers will be doing the same. Observing this sky event takes little effort. You can watch the whole thing or just part of it. You can use a telescope, binoculars, or just your eyes. You can view it from the darkest site on Earth or from the heart of a city.

And if you'd like to add a fun cultural reference as you gaze upon our lone natural satellite immersed in Earth's shadow, remember the final spoken words in Pink Floyd's monumental album *Dark Side of the Moon*: "There is no dark side of the Moon, really. Matter of fact, it's all dark."

Michael E. Bakich *is a senior editor of* Astronomy *who has enjoyed dozens of lunar eclipses, several while listening to Pink Floyd.*

USING SOLAR POWER to view the stars

This cutting-edge home and observatory showcase optical astronomy and sustainable technology.

text and images by Alan H. Midkiff and Emily A. Mailhot

Now more than ever, the global production and consumption of energy pose challenges to everyday living. Whether it is sky-high costs, questionable availability due to unstable political situations, or storm-related outages overburdening an antiquated power grid, the modern reality of energy uncertainty seems to be here to stay for the foreseeable future.

Groups and individuals have made efforts to mitigate this volatility by considering more sustainable energy sources. Being mindful of the environment should be important to those with a passion for astronomy because low-energy, dark-sky conditions are crucial to the observing experience. At the Midkiff home in northwest New Jersey, I have tried to minimize our dependence on outside energy sources to create an environment that not only uses sustainable technologies for day-to-day living, but also enhances our astronomy-related activities.

We are fortunate to live in one of the few remaining relatively dark-sky sites in the tri-state area (New Jersey, Pennsylvania, and Delaware). Although light pollution has deteriorated our night sky during the past decade, on occasion we still enjoy a horizon-to-horizon Milky Way panorama. I grew up in the area and became involved in astronomy in my youth; thus, incorporating an observatory within my home has been a long-term goal.

Breaking ground

In 1995, with help from friends and family, I began constructing the first of two homes on a 31-acre hilltop lot. Although the 750-foot (229 meters) elevation is not impressive by western standards, the location is high enough to afford a view of the Delaware Water Gap to the west and the Jenny Jump State Park observing site of the United Astronomy Clubs of New Jersey (www.uacnj.org) 4 miles (6.4 kilometers) to the south. Unique features of this house include a two-well geothermal heating/cooling system and a 4 by 7 by 25 foot (1.2 by 2.1 by 7.6 meters) concrete tower constructed through the center of the house, which serves as a footing support for the telescopes in the rooftop observatory.

Designing an observatory that operates in an environment replete with the full

The first telescope housed in the rooftop observatory was this 16-inch f/5 equatorially mounted Newtonian reflector. After a few years of using it, Midkiff sold it and purchased a 25-inch reflector.

The first observatory sits atop a 25-foot-high (7.6 meters) concrete tower in the center of the house but isolated from it to prevent vibration. You can see the secondary cage of Midkiff's 25-inch reflector sticking straight up at center before he relocated the scope.

Co-author Emily A. Mailhot poses atop an observing ladder to lend a sense of scale to the 25-inch Newtonian reflector.

range of normal household activities required careful consideration. I isolated the concrete tower from the house framing and other structures to uncouple the telescope mounts from vibrations induced by running children and dogs. Likewise, to keep the air mass over the roof thermally stable, I used off-white shingles that minimize re-radiation after sunset and inserted R-38 insulation between the roof rafters.

Two solid concrete anchor piers cap the tower. Originally, I mounted a 16-inch f/5 Newtonian reflector for deep-sky work to one of them and a 7-inch f/7 apochromatic refractor for planetary and double-star viewing to the other. It didn't take long for local schools to become aware of the facility, and although the 11 by 13 foot (3.4 by 4 meters) roll-off roof observatory could hold approximately a dozen observers comfortably, there were times when 30 or more people packed in. The larger groups started with the apparition of Comet Hyakutake (C/1996 B2) in the winter of 1996.

Alan H. Midkiff *is an aeronautical research engineer at the Massachusetts Institute of Technology (MIT) and is a 767 captain for American Airlines.* **Emily A. Mailhot** *is president of the North Warren Regional High School Astronomy Club. Her research includes contributing light-curve data to the Planetary Astronomy Lab at MIT for a study of binary asteroids.*

Modest power needs

The geothermal system extracts heat from well water at a temperature of 50° Fahrenheit (10° Celsius) and produces 70° F (21° C) air by employing an expansion/compression cycle. The 37° F (3° C) discharge is returned to a second well located about 100 feet (30.5m) from the first, then cycled back through the aquifer. Because geothermal systems use compressors and pumps that require significant electricity, I supplemented the home's utility consumption with a photovoltaic (PV) power system, which converts sunlight into electricity.

The initial PV installation produced a modest 3.6 kilowatts (kW), but at the time there were few like it. After site visits by representatives from both the state energy commission and the local power company, it became the prototype for the New Jersey solar rebate incentive program. More recent PV system component upgrades include a 150 kW/hour battery bank and charge controllers that can supply house loads for up to three sunless days. A dual inverter system changes the 48-volt DC panel/battery bank voltage to 220-volt AC power.

The system also ties into the grid to sell back daytime overproduction to the utility company. Finally, because the battery bank backs up all the circuits supplying the

Midkiff's geothermal system produces 70° Fahrenheit (21° Celsius) air from well water at a temperature of 50° F (10° C).

observatory, visitors can enjoy in-house nighttime viewing of the darker skies that power outages offer. Lately, these seem to be occurring on a more frequent basis due to unpredictable grid availability.

More power, more aperture

Both astronomy and solar power involve capturing energy. In the case of each system, the performance rises in relation to the area of the collectors. And just like in astronomy, it's easy to get energy-based "aperture fever," which leads to increasing array sizes and power production. Within a few years of the initial installation, I added 2 kW to the PV array to help offset the energy demands of a second home I constructed on the property.

My observing appetite also motivated me to pursue larger astronomical instruments. I sold the 7- and 16-inch telescopes and used the proceeds to purchase a 25-inch f/4.9 JMI NTT Newtonian reflector. Within a year, I upgraded the alt-azimuth drive system to Byers gears and Comsoft PC-TCS telescope control. I bolted the 25-inch to the north pier, but, due to

This observatory, which Midkiff built to house his 25-inch reflector, has wheels that lets the whole building roll off. This design allows celestial views closer to the horizon and accommodates larger groups.

This photo shows the inverters (that convert the direct current that the photovoltaic array produces to more usable alternating current) and the battery bank that stores power for evening or cloudy-day use.

The newest energy-saving addition is this hybrid solar hot-water system. On sunny days, it can heat both houses on the property. Here, a visiting school group poses underneath it.

space limitations, some of the sky was cut off. This led to the next upgrade.

Moving out, maxing out

Increases in both the size of the telescope and the visiting public groups led me to construct a larger observatory building in one of the hayfields. When I finished it, I moved the 25-inch reflector there. To accommodate bigger crowds, the observatory's design lets the entire building roll away. A 220-volt service runs through a 400-foot (122m) underground conduit, which, like the rooftop facility, ties to the inverters for uninterrupted power.

During the past few years, I expanded the PV system to 25 kW, which fully balances our consumption and eliminates any reliance on fossil fuels. In addition, I have installed a hybrid solar hot-water system to offset the heating load of the geothermal units. Three hundred evacuated solar hot-water tubes and 200 square feet (18.6 square meters) of flat-panel collectors harvest enough energy on sunny days to satisfy the heating requirements of both houses. They also store enough excess heat in a 550-gallon (2,082 liters) insulated tank to delay activation of the geothermal units typically until late evening.

Current activity

In the past five years, I joined Emily A. Mailhot to expand our public outreach by establishing an astronomy club, the North West Jersey Amateur Astronomers (www.nwjaa.org), which oversees a student chapter at the local high school. Both operate under a 501c(3) nonprofit corporation we formed, the Star View Hill Education Center (www.starviewhill.org). Meetings take place at the observatory, with presentations by accomplished amateurs and university researchers followed by observing.

Recently, we established a collaborative relationship with Michael Person of the Planetary Astronomy Lab at the Massachusetts Institute of Technology to provide light-curve data for use in binary asteroid research. In addition, when favorable shadow path conditions exist, we conduct occultation timings used in conjunction with data from other area observatories.

Future plans

To enhance our research activities and ongoing public outreach, we plan to construct a larger domed observatory at the field site that will accommodate a larger telescope and allow remote observing. On the energy side, our year-round average wind speed of 11 mph (18 km/h) should be able to keep a wind turbine producing sufficient power to enable us to harvest energy even at night while we observe the heavens from a "green" observatory.

Alan Midkiff's photovoltaic system initially produced 3.6 kilowatts of power. After several upgrades, it now yields 25 kilowatts.

How Terry Mann captures

Author Terry Mann travels all over the United States to capture the beauty and mystique of both earthly and celestial wonders.

Terry Mann *is a former president of the Astronomical League and an avid astroimager. You can purchase her night sky photographs at www.elusivelightimages.com.*

I can't recall a time when I wasn't fascinated with the night sky. Although I was too young to remember, my mom once told me that I noticed the stars when I was very small and asked endless questions about them. I do remember a time in grade school when I spotted my dad's Polaroid camera. I had strict orders not to touch it, but I wanted a picture of the Moon. Later that evening, I slid it under my jacket, and outside I went. As soon as the flash went off, my dad came out the door. Instead of expressing the anger I anticipated, he explained why I didn't need to use a flash to take the picture. An astrophotographer was born that night.

Early ambitions

My imaging began in earnest in the 1980s. I started with a used Criterion RV-6 Dynascope reflector. I remember trying to get the camera attached and focused and the telescope balanced on my first night under the stars. It was in the dead of winter, probably around –10° Fahrenheit (–23° Celsius). As I shot the Moon, I realized I needed to learn the sky so I could find other objects to focus on. That night also helped me decide what equipment I would need to continue imaging.

In the beginning, I wanted to image the deep sky. And while I still would like to do that someday, I quickly found joy in "Earth and sky" imaging. I have a feeling of awe as I stand under the dark cloudless heavens. So while I still have multiple telescopes and an observatory in my backyard, my primary focus has been on the camera.

For years, I used a Pentax K1000 single-lens reflex (SLR) camera with 35mm film. It was and still is a great piece of equipment. In fact, I still have it and a couple of my best lenses. I also carried a Pentax 645 SLR on many trips as I began to travel to shoot the night sky. In those days, imaging was harder. I hypersensitized my own film

Earth and sky

This photographer takes on the risks lurking in a dark wilderness to image night sky wonders.

text and images by Terry Mann

The summer Milky Way dazzles above Bryce Canyon, Utah, despite the small amount of nearby light pollution. To capture this popular portrait, which she calls "Cosmic Rainbow," the author stitched together three separate images.

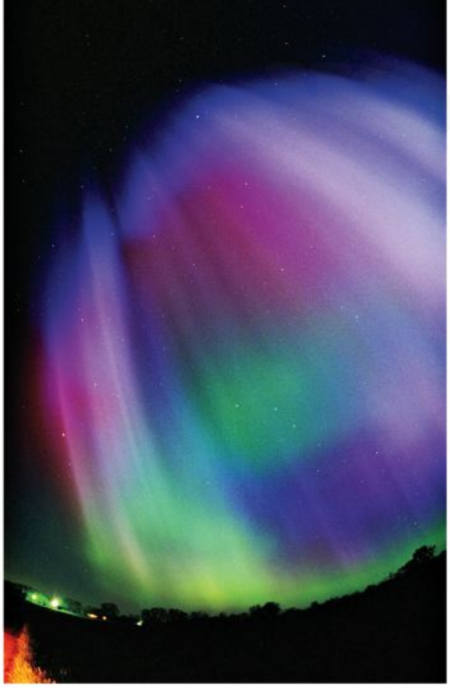
— a process that causes film to record more of an object over a given time — and had a darkroom. But then the digital age came.

Elusive light

Today, I use Canon's EOS 5D Mark III and EOS 650D digital SLR cameras; the "live view" and instant "preview" features have made imaging a lot easier. For my wide-angle shots, I attach a Tokina 11–16mm f/2.8 AT-X116 Pro DX Digital Zoom Lens to the 650D or a Rokinons14mm Ultra-Wide Angle f/2.8 IF ED UMC Lens or 35mm f/1.4 Aspherical UMC Wide Angle Lens to the 5D.

While I do image many astronomical events, my focus is still on capturing Earth and sky portraits as well as aurorae. The first time I saw an aurora was in my backyard in Ohio. When I imaged "Patchwork Aurora" (p. 60), I could see the light pulsating; it almost seemed to be alive. That experience was the driving force to get me

A world of green started in the sky over Alaska the morning of St. Patrick's Day 2013. Many times that day, aurorae exploded into a swirling mass of colorful light.



A "patchwork" aurora dazzles above a country road in Ohio. Although the author has traveled to Alaska to capture the northern lights, she has seen many such brilliant displays from her home state.

The Big Dipper and a sporadic meteor provide a stunning backdrop to New Mexico's Karl G. Jansky Very Large Array, a radio observatory composed of 27 antennas.

The author considers Bryce Canyon in Utah the most beautiful place she has visited. To create this image, she hiked down into the canyon and used a dim light to paint the rocks in the area during a long exposure.

Old Faithful in Wyoming's Yellowstone National Park erupts under a starry sky. According to the author, this was much to the surprise of a little girl passing by with her father, as she believed Old Faithful needed to sleep at night, too.

to Alaska in March 2013 — perfect timing, as a strong coronal mass ejection, which is a massive blast of the solar wind into space, impacted Earth. I have never seen an aurora dance with such brilliant light.

For both aurora images and Earth and sky portraits, there is something about being able to show the beauty just beyond what the eye can see. The elusive light is there, and a camera can bring out more detail. Plus, people seem to relate to the image if it's composed around something they recognize. Because I do a lot of public speaking using my images, capturing such natural beauty is important. Some people have never seen truly star-filled skies and do not understand light pollution. I like to be able to show what we are losing. "Cosmic Rainbow" (p. 58–59), for example, is a special image for me. It shows the Milky Way in a way most people never see it. I get a lot of positive feedback about that image. If it can make people stop, look, and question, that image did the job!

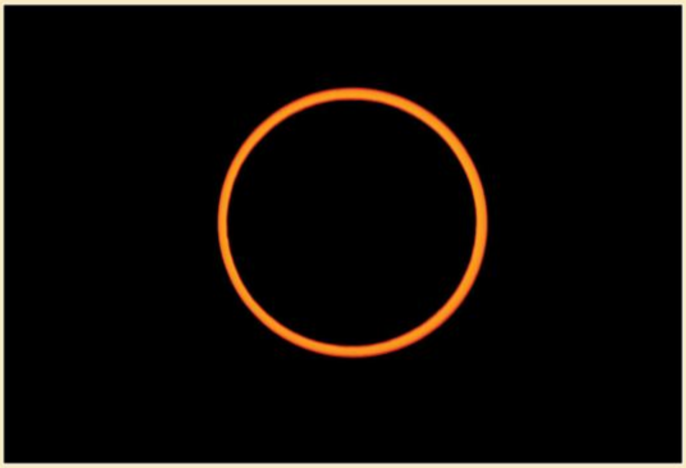
But to capture such an image requires a lot of planning — and some luck. It's important to first find the limits of any equipment before even leaving home. I know exactly where to set my camera lens to bring the stars into focus, and I know how far I can go with any setting to get the results I desire. To do this, though, I also have had to get used to working in the dark and using a red flashlight.

Planning goes beyond equipment, though. Scouting imaging locations during the day is key so I have an idea where to go at night because everything looks and sounds a little different in the dark. I also consider rise and set times of the Sun and the Moon and what the current lunar phase is. If I'm in a park, I let the rangers know my plans. I even get feedback from them to see if they know of a better spot to choose. And most importantly, I consider safety, always bringing a first-aid kit with me and making sure someone knows where I'll be imaging.

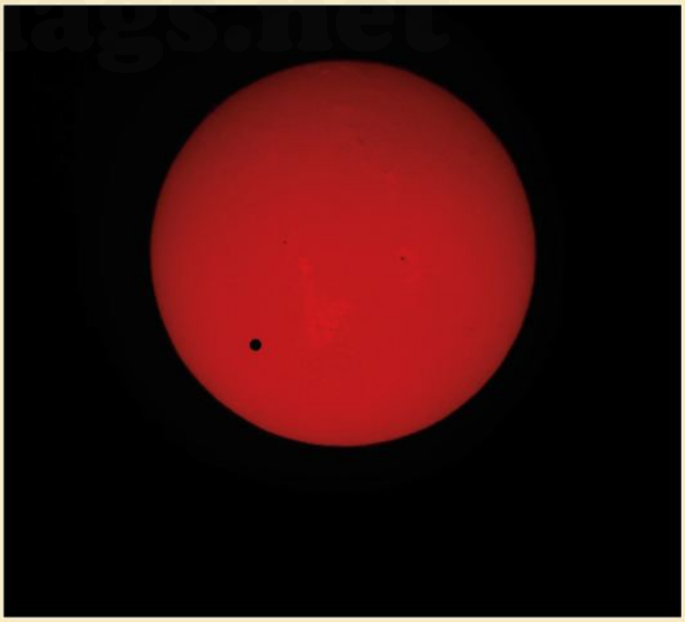
Outdoor adventures

I usually spend my vacations at dark-sky sites or star parties imaging or just soaking up the starlight. My "lodging" has ranged from hotels to cars, and my precautions have included a purchase of my first pair of

IMAGING THE SUN AND THE MOON



A ring of fire hung over the desert Southwest on May 20, 2012. The author captured this annular solar eclipse from Lake Powell in northern Arizona.



Venus becomes a blemish on the solar disk in this image of the planet's transit of the Sun on June 5, 2012. The author captured the event through a solar telescope from Payson, Arizona.

The total lunar eclipse of October 27, 2004, involved a brick red Moon that was difficult to see when Earth's shadow completely covered it.

On an evening in March 2010, the author was able to capture a beautiful Sun pillar, an atmospheric phenomenon that can occur near sunset or sunrise. Sunlight reflecting off millions of ice crystals causes such a display.

snake-proof boots. They really are priceless when hiking around the desert.

People are curious when they find me out at night with a camera. Explaining to the police why I am out in the middle of nowhere, in the dark, alone, and with a camera must sound pretty suspicious. After they have shined their lights on my equipment, most of them ask me about my quest. Armed with identification, sample images, and business cards, I have been able to convince them I am harmless.

While people are pleasantly curious, I have had my share of tense moments with the local wildlife. During an imaging session in Yosemite National Park, for example, I had my first encounter with a bear. Luckily, it wasn't as interested in me as I was in it. I jumped in the car and turned the lights on it to see it better. He was huge, and his fur shimmered as he walked. It didn't take me long to pack up and find a new trash-free location.

I have been buzzed by bats and surprised by coyotes — even injured running from them in my own backyard. Once, I had a raccoon try to break into my car. He left paw prints all over it, especially around the sunroof. People were taking pictures of the scene as I walked out the next morning. Still, nothing beats being in the wilderness imaging the night sky.

Worth the wonder

To maintain such a lifestyle, admittedly some of my priorities have changed. Sleep is the first thing to go when I run short on time, and camera gear takes priority over everything else when I fly. Sure, I can run the camera remotely and catch up on some sleep, but there is something about looking at the sky. It's hard to put into words the feeling of being out there, in the wilderness, under the stars. Some of my best memories are from imaging alone in the night. Silence is at times beautifully deafening. I still have the wonder that little girl had when she took her first astrophoto. My mom and dad wouldn't be surprised.

SEE MORE OF MANN'S NIGHT SKY PHOTOGRAPHY AT **www.Astronomy.com/toc.**

Astronomy tests Meade's new 10-inch SCT

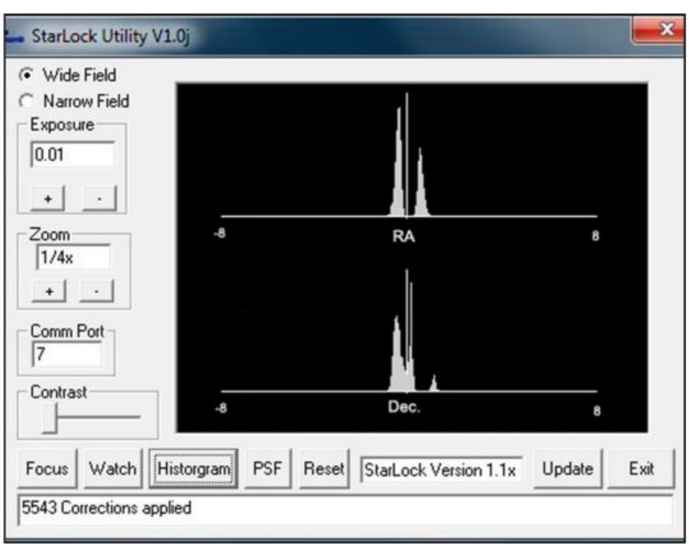
Great optics, high-quality construction, and serious aperture make the LX850 a winner. **by Craig and Tammy Temple**

Meade's LX850 package contains the company's 10-inch Advanced Coma Free Schmidt-Cassegrain telescope optical tube assembly, a heavy-duty mount, an ultra-stable tripod, the StarLock integrated guider, and more. MEADE INSTRUMENTS

One thing we have learned in this hobby is that the mount is a setup's most critical component. Even the finest telescope can produce poor results if it rides atop an inferior mount. Unfortunately, big, beefy mounts that offer precise guiding and carry large optical tube assemblies (OTAs) can get quite expensive. If you are looking for these features in an integrated package at an affordable price, the Meade LX850 may be for you.

The shipment has arrived

We were excited to test the LX850 package, which contains the Meade 10-inch Advanced Coma Free Schmidt-Cassegrain telescope OTA, the LX850 mount, an adjustable height tripod, the StarLock integrated guider, and the company's Zero Image Shift Micro-focuser. Upon its arrival by truck on a pallet, we were in awe of the box's size and could only imagine the beast that lay within.



StarLock is an integrated two-camera sensor array that provides four primary functions: full-time automatic guide star selection and autoguiding, ultra-precision pointing to an accuracy of 1', drift alignment assist to automatically calculate how the mount must be adjusted for polar alignment, and Light-switch alignment to select and automatically center alignment stars using its two cameras. MEADE INSTRUMENTS

Like two kids on Christmas morning, we eagerly opened boxes and confirmed that it was indeed a beast. The sheer size of the tripod dwarfed anything we had used so far in our journey through this hobby. Once we assembled the setup, its fit, finish, and robustness impressed us.

Preparing for first light

As many in this great hobby know, days of clouds have a way of arriving the same time as new gear. Much to our surprise, though, our skies cleared, so we went through the steps to ready the system for use. As with any setup, balance plays an integral part in the mount's performance. So we balanced just as we would have with our own equipment, with one difference — the clutches on the LX850 adjust with an Allen wrench. While this could have been a difficult task for us to perform in the dark, we succeeded by using the included tool and a flashlight.

Next, we performed polar alignment and calibrated the mount's go-to drive. Instructions were clear and concise, but not having a polar alignment scope made this a different experience for us. The process was straightforward, however, and relatively easy. In fact, the most difficult and time-consuming part was centering Polaris (Alpha [α] Ursae Minoris) in an eyepiece using only the azimuth and elevation knobs.

First light — visually

Eager to test the drive's accuracy and see what the optics had to offer, we slewed the LX850 to our first target, ringed Saturn. Initially, we thought something went awry when the hand paddle displayed "Auto Ctr Star." We soon realized that StarLock was refining the go-to to make locating future objects more accurate. Once on

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Craig and Tammy Temple *are a husband-wife team who have enjoyed the great hobby of astrophotography since 2007.*

PRODUCT INFORMATION

Meade LX850 system

Optical configuration: Advanced Coma Free Schmidt-Cassegrain telescope
Aperture: 10 inches
Focal ratio: f/8
Focuser: Crayford-style, 7:1 reduction
Guider: StarLock full-time automatic
Mount: German equatorial
Computer: *AutoStar* hand controller with 144,000-object database
Tripod: Folding, adjustable height
Accessories: 8x50 finder scope, Series 5000 2" star diagonal, 25mm HD-60 eyepiece, anti-vibration pads, Zero Image Shift Micro-focuser
Price: $7,999
Contact:
Meade Instruments
27 Hubble
Irvine, CA 92618
[t] 800.626.3233
[w] www.meade.com

CRAIG AND TAMMY TEMPLE

The authors created this image of the Bubble Nebula (NGC 7635) by attaching a CCD camera to the LX850 and stacking nine 20-minute exposures each through Hydrogen-alpha, Oxygen-III, and Sulfur-II filters.

Saturn, StarLock located a star within the field of view and started guiding. This was a real treat because it kept Saturn centered while we enjoyed the great views the optics afforded.

With the included eyepiece, Saturn was clear, and we could see the Cassini Division easily, as well as four of the planet's moons. We tried a variety of eyepieces and Barlow lenses, and all views were great. To really put the optics to the test, we slewed to Albireo (Beta [β] Cygni). Once again, a dead-on go-to! The scope split this beautiful double star nicely, and the blue and gold colors were remarkable.

First light — imaging

After many subsequent cloudy nights, the skies cleared for some imaging. We set up the LX850, performed polar alignment and go-to calibration, connected our CCD camera, and balanced everything on the mount. Because we would be autoguiding while imaging, the Auto Rate Calibration (ARC) feature intrigued us.

Using it, StarLock monitored an eastern star near the celestial equator, checked various guide rates in an effort to determine which would be best for current conditions, and then set that rate based on the ARC's findings. This is a fine feature and works well to get you going, but we found that we had to adjust the rate slightly as our target traversed the sky.

Then we learned that a prerequisite to using the ARC is to perform the Permanent Periodic Error Correction (PPEC). It's another relatively simple automated process, and it took us only around 25 minutes for three iterations. Since the PPEC is "permanent," you don't have to repeat it. Note, however, that additional runs will refine the correction.

Next, we slewed to the 1st-magnitude star Vega (Alpha Lyrae) and focused using the microfocuser. While it provided nice resolution with no slippage, it did sag a bit under our big camera's weight, so we had to remove the microfocuser from the imaging setup. One other "uh-oh" was finding that initial polar alignment and guiding were not enough to give us nice round stars, so we delved into the telescope's auto drift alignment.

We were pleasantly surprised when we saw how Meade had made this process almost as easy as falling off a log. We simply used the hand paddle to select the drift alignment feature. The mount slewed to a star near the southern meridian, monitored its drift for a bit, then displayed the direction and number of turns we needed to make to the azimuth knob.

After we made the adjustment and indicated with the hand paddle that the adjustment was done, StarLock monitored the star's drift again and indicated the turns needed, if any. This continued until it displayed "No turns needed," at which point we used the hand paddle to indicate completion. The mount then slewed to an eastern star near the celestial equator and followed the same process, only now having us make turns to the elevation knob. Once "No turns needed" appeared again, drift alignment was complete.

We ran our imaging sessions like usual, with a few exceptions. Having removed the microfocuser, we focused by hand using a Bahtinov mask. This task was easy because the manual focuser was smooth yet firm enough to find that sweet spot. Guiding was a bit different from our norm, but we succeeded using StarLock and the graph in the *AutoStar* Software Suite. The planetarium software was a bit lackluster, but it functioned well and got the job done.

Summing up the system

The Meade LX850 is a high-quality package for both the visual observer and imager. The optics are terrific, the drive is precise, and the fit, finish, and operation are top-notch. Although we had a few issues with certain minor aspects, we attribute them to the lack of hands-on time to flesh them out.

Finally, although Meade lists this as a portable system, we feel the LX850 would perform best in a permanent setup. It's a robust system with great automated features in an affordable package.

COSMIC**IMAGING**

BY ADAM BLOCK

Comet construction

Unlike most astronomical targets, comets move quickly. This apparent speed can make both the acquisition and processing of the data challenging. In this column, I'll describe how to create composite images of comets that appear as snapshots without smeared stars or blurred cometary details.

Indeed, a single exposure is the most desirable way to acquire the data. One long exposure, however, is generally not adequate to capture the faintest and most exciting part of a comet — its tail. This issue becomes even more challenging because monochrome cameras require exposures through red, green, and blue filters.

The way to avoid these issues is to take multiple exposures of the comet. Each should be as long as possible without showing significant comet trailing. Separate each exposure by the amount of time necessary for the comet to move 10 or more pixels. For focal lengths between 500 and 4,000 millimeters, this works out to be between four and 10 minutes. This technique works for one-shot color cameras as well as tri-color imagery.

Maximize the length of the base exposures of the comet, but don't introduce trailing, which I judge as being more than five pixels. Of course, ultimately this depends on the motion of the comet, but using the numbers above, try times from two to five minutes.

To acquire tri-color data, expose the comet while cycling the filters among red, green, and blue. By capturing images this way, each time you take a red picture, the comet will have moved the required 10 pixels before you take the next red shot. Put a delay between exposures if necessary.

Once you calibrate all of the exposures with darks and flats, you should register and combine the data set in two different ways. First, align the images using the stars. Before averaging the images, use a strong rejection algorithm, such as the "Poisson Rejection" feature in *CCDStack*. And here's a tip: Standard processing requires that you normalize the data before you do any form of rejection. Programs vary as to how this is done, but you must do it to get the best results.

At this point, you'll have an image with stars and a faded, mostly rejected comet. Then, with the same initial data, align on only the comet. This time when you combine the image using the algorithm, only the comet will remain and the stars will disappear. Even combining the data with the "Median" setting will work, but you'll get a better signal-to-noise ratio using a more robust rejection technique that averages values after removing outliers.

Once you create these two images, bring them into *Photoshop* as two layers and blend them together. Regarding the image of the star field with a faded comet, it is possible to remove or further fade the parts of the comet still visible.

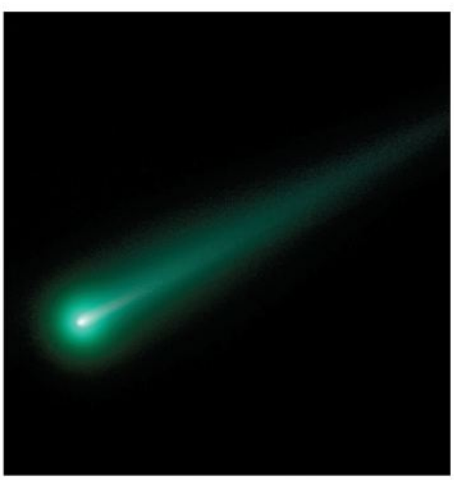
Then, blend the layers using the "Lighten" blending mode. The comet layer (the one with no stars) will overlay on the star layer. Raise the black level and make the sky dark in the comet layer so the sky values don't add to the image but only the comet is visible.

At this point, you should be close to the goal of a composite image. There may still be discontinuities between the two images. If so, often a simple mask with a strongly blurred edge on the comet layer will make artifacts nearly invisible.

FROM OUR INBOX

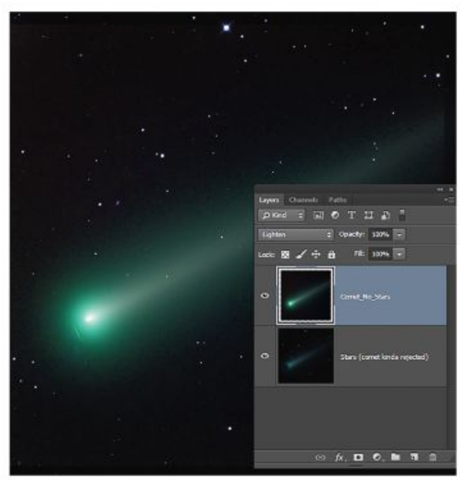
Sea stargazing

My wife and I recently took a cruise to the Bahamas. I realized that the ship would be a great place to view the night skies. The first night, I went out, and although I could see better than in my part of light-polluted Miami, a number of bright lights drowned the open-sea sky out. I approached several of the ship's officers and explained that this was a show that occurs every night that they don't have to hire performers for. If people could be seated on recliners on the dark top deck of the ship, see the stars and constellations during a short nontechnical lecture, it could spur interest in both astronomy and cruise lines. Maybe next time. **— Will Harden,** Miami



To create this image, the author used a rejection technique common to image-processing software. It shows just the comet without the starry background. You can see a completed image at www.skycenter.arizona.edu/gallery/SolarSystems/ison_10082013. ALL IMAGES: ADAM BLOCK

This image, which the author also created by using a rejection technique, shows mainly the stars with a faded comet. You'll find a completed comet image different from the one referenced in the caption at left at www.skycenter.arizona.edu/gallery/SolarSystems/ison_11082013.



The author blended the two images to the left together using "Lighten" mode in *Photoshop*. In his technique, the layer with the comet overlays the one with the stars. The screen shot (inset) shows that he had not yet removed the comet entirely from the bottom image.

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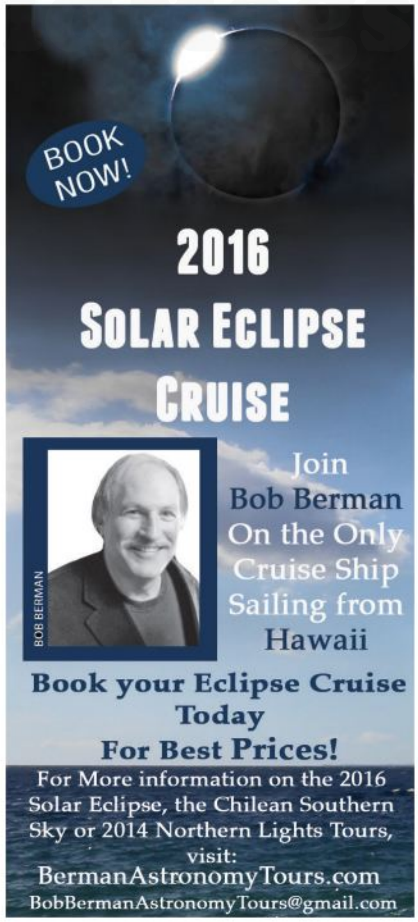
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ASTRO**SKETCHING**

BY ERIKA RIX

Processing your sketch

Elongated stars, stray markings, and uneven blending — sound familiar? After all, we frequently sketch in damp or cold conditions under dim lighting, often with stiff fingers — then throw fatigue into the mix.

So, this month I want to talk about cleaning up scanned sketches with simple photo-editing tools. I'll use the interacting spiral galaxies called the Antennae (NGC 4038/9) to demonstrate how.

This pair lies in the constellation Corvus. To find them, draw a line from Algorab (Delta [δ] Corvi) to Gienah (Gamma [γ] Corvi) and extend it another 3.5°. The two galaxies began on a collision course a few hundred million years ago and got their collective name because of the filamentary extension uncurling from each nucleus.

The Antennae's unique shape makes it an exceptional object to observe. In fact, it sheds some light on what may occur when our own Milky Way encounters and begins to merge with the Andromeda Galaxy (M31) some 4 billion years from now.

Through a 6-inch telescope, you'll see only a faint puff of light with a V-shaped opening to the west-southwest. A 10-inch scope reveals NGC 4039 to be long and slender compared to its northern companion. NGC 4038 has a thick comma shape that curves southward. A bright loop that becomes nodular through a 16-inch scope surrounds a dark central patch within it. In larger telescopes, look for hints of the "antennae" extending from the eastern base.

OK, you've made a sketch of the Antennae (although the following steps will work for any deep-sky object). Create a high-resolution scan of your sketch, and then use your software's "Clone" tool to remove unwanted markings (including any notes you made) from the scanned copy. Clone-stamp areas near the marks with a soft, round stylus so the background blends naturally.

Do the same to elongated stars so that you shorten them without changing their magnitudes. You can use the "Blur" tool for uneven blending within the bodies of galaxies or when working with nebulosity.

To softly illuminate the brighter stars, use the "Eyedropper" tool to match the stars' colors. Then select a soft, round brush with minimal opacity to produce the star glow. The brush's size should be slightly larger than the star.

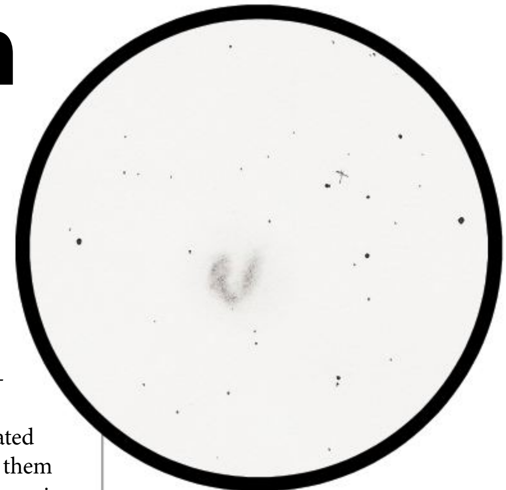
Next, invert the sketch so the stars will appear white against a black background. If the contrast isn't correct after inverting, you can adjust it with "Curves," "Brightness/Contrast," or the "Exposure" setting. Be careful that you don't lose nebulosity or faint stars in the process. Finally, you can add star color with the "Color Replacement" tool.

In addition to *Photoshop*, you can choose from several photo-editing software packages, including freeware like *GIMP*. Others have trial versions, allowing you take them for test drives before committing to a comprehensive suite.

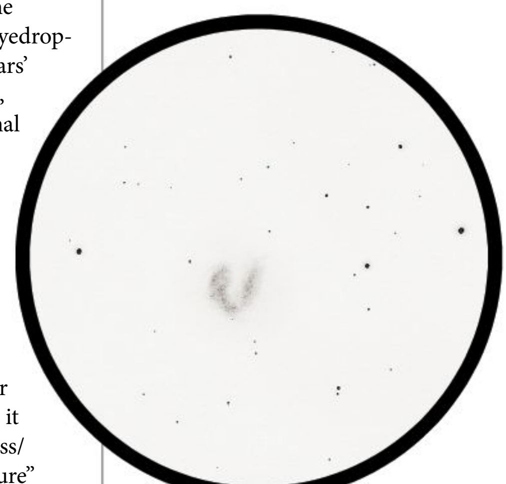
It's important to check the calibration of your monitor for settings like "Gamma" and "Contrast" if you share your sketches electronically. You can find monitor tests at Han-Kwang Nienhuys' website, http://www.lagom.nl/lcd-test.

The amount of processing you do — if any — depends on your personal preferences. Your sketch is an observational record, and you have to be careful not to add or take away from it during the editing process.

Do you have a sketching question? Send me an email at erikarix1@gmail.com.



This image is the author's original scan of her Antennae (NGC 4038/9) sketch, which she completed while observing through a 16-inch reflector with an eyepiece that yielded a magnification of 225x.



This image is the same sketch after the author used software to clean it up. She removed stars in the wrong places, corrected the shapes of elongated stars, added some glows around bright stars, and adjusted the overall contrast.

As a final step, the author used *Photoshop* to invert her processed sketch and depict her view through the eyepiece (white objects against a black sky). ALL SKETCHES BY ERIKA RIX

BY KARRI FERRON

MOBILE UPDATES » Scan the code to access the latest news and observing info from your mobile device.

Featured video

"How to observe a lunar eclipse"

No one has seen a total eclipse of the Moon since December 2011, but 2014 brings back the special celestial phenomenon in spades. The year hosts not one, but two total lunar eclipses — both visible from at least part of North America. The fun kicks off the night of April 14/15, when the Full Moon dips deeply into Earth's shadow for the first time in 857 days.

To help prepare for the event, check out Senior Editor Michael E. Bakich's video "How to observe a lunar eclipse." He starts with a detailed introduction and demonstration that show what happens during a lunar eclipse — and why one doesn't occur every month, even though a Full Moon does. Then, Bakich explains what terminology you'll need to know and the differences between these events and their counterparts, total solar eclipses. And finally, he explores why it's easy to observe and photograph lunar eclipses and what to look for as you're watching these special events. So check out the video before April 14 and again before 2014's second occurrence October 8 at **www.Astronomy.com/lunareclipse**, and enjoy this year of the lunar eclipse.

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OBSERVING TOOLS

Spring observing videos

Each season, *Astronomy*'s editors provide you with three videos outlining showpiece objects currently in your sky. Senior Editor Richard Talcott gears one video toward beginning observers and easy targets, including Mars, Saturn, and April's lunar eclipse. In another, Senior Editor Michael E. Bakich focuses on objects you can see through a small telescope, including the open cluster M67 and Bode's Galaxy (M81). And finally, Editor David J. Eicher shares 10 of his favorite springtime deep-sky targets, from the Hercules Cluster (M13) to Centaurus A. Check them all out at **www.Astronomy.com/seasons**.

COMMUNITY

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BEHYAR BAKHSHANDEH

Browse thousands of astroimages like this one of Thor's Helmet (NGC 2359) and submit your own at **www.Astronomy.com/readergallery**.

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The secret lives of supermassive stars

They live fast and die young — in fantastic explosions

ESO/M.-R. Cioni/VISTA Magellanic Cloud survey/Cambridge Astronomical Survey Unit

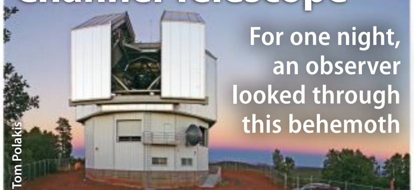
Peering inside a monster galaxy

X-rays tell a cataclysmic tale about the inner workings of M87

Tod Lauer/Sandra Faber/NASA

A dream night with the Discovery Channel Telescope

For one night, an observer looked through this behemoth



Tom Polakis

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Astronomy magazine

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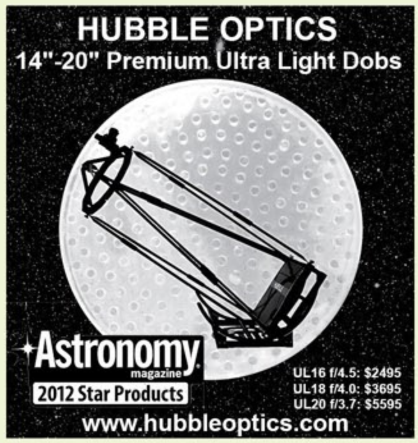

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READER GALLERY

1. LOVEJOY DAZZLES

The way Comet Lovejoy (C/2013 R1) performed in December made imagers forget their disappointment in Comet ISON's (C/2012 S1) disappearance. (8-inch Astro Systeme Austria astrograph at f/2.8, FLI PL-16070 CCD camera, LRGB images with 5 minutes of exposure through each filter, taken [left to right] December 12, 2013, at 4h14m UT, December 13, 2013, [three-frame mosaic] at 3h41m UT, and December 14, 2013, [two-frame mosaic] at 4h20m UT, from Jauerling, Austria) • ***Gerald Rhemann***

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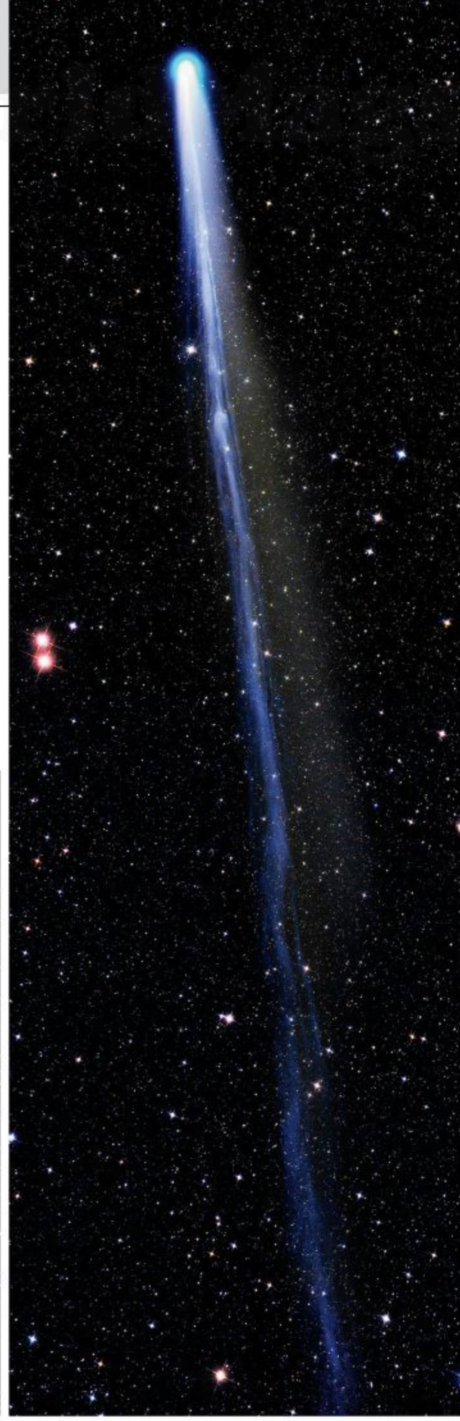

2. THE NEAR AND FAR SKY

These photographers set up their camera and captured a full hour of auroral action in the northern sky. The star trails show Earth's motion during that hour. Every now and then, a car would pass by to the lower right on a nearby country road. The headlights lit up the autumn colors in the trees. (Canon 6D DSLR, Canon EF 24–105mm f/4L IS USM lens set to 24mm and f/4.5, ISO 2000, one hundred and eighty 20-second exposures, stacked, taken October 8, 2013, from Georgian Bluffs, Ontario, Canada) • ***Steve and Joan Irvine***

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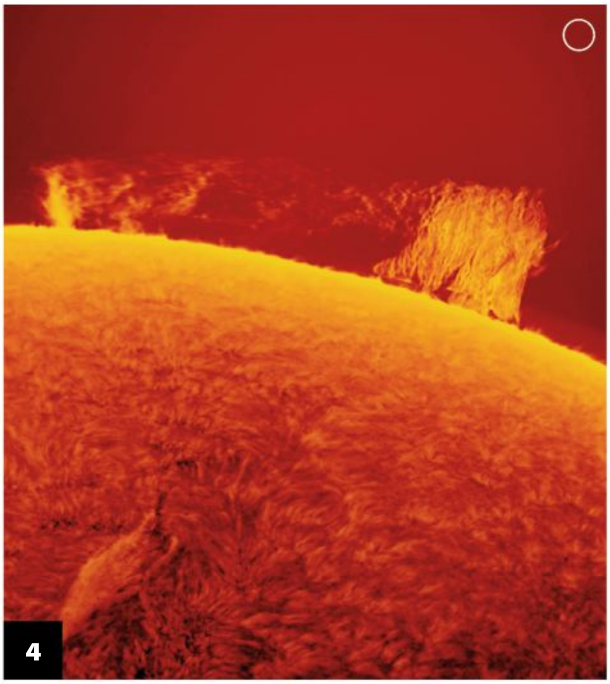

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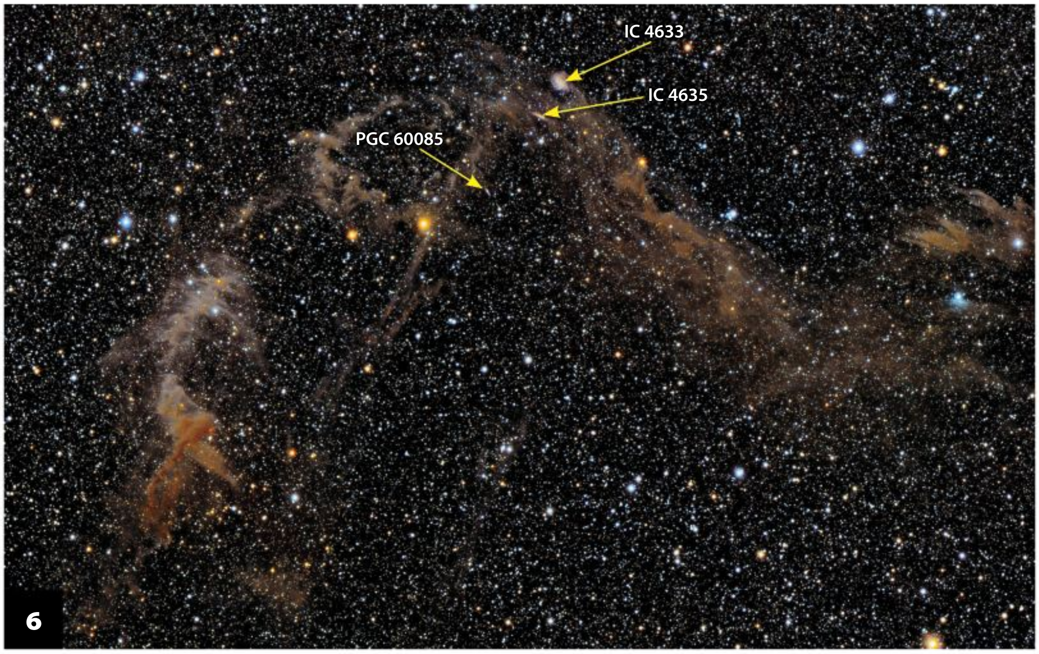

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3. THE FLYING BAT
The imager thought the large red emission nebula Sharpless 2–129 resembled a flying bat descending on the bluish reflection nebula van den Bergh 140. Both objects lie in the constellation Cepheus the King. (2.8-inch Borg 71FL refractor at f/3.9, Quantum Scientific Instruments QSI 583-20 CCD camera, three-panel mosaic, each an Hα LRGB image with exposures of 120, 90, 15, 15, and 25 minutes, respectively)
• ***John A. Davis***

4. PROMINENCE CURTAIN
The Sun was active last year, as shown in this image of a huge prominence. The small circle represents the size of Earth. (4-inch Vixen ED100SF refractor at f/24, Point Grey Chameleon Mono CCD camera, DayStar Quantum 0.5-angstrom Hα filter, taken August 13, 2013) • ***Paolo Porcellana***

5. BOOM!
Australian amateur astronomer John Seach discovered Nova Centauri 2013 (V1369 Cen, arrow) on December 2, 2013. The bright star to its right is Hadar (Beta [β] Centauri), and Rigil Kentaurus (Alpha [α] Cen) shines at lower right. (Canon EOS Rebel T3i DSLR, 40mm lens at f/4, ISO 1600, 3-minute exposure, taken December 5, 2013, at 3:16 A.M. local time, from San Antonio de Areco, Argentina) • ***Luis Argerich***

6. JACOB'S LADDER
This rarely imaged region only 13° from the South Celestial Pole lies in the constellation Apus the Bird of Paradise. Several galaxies inhabit the area, but the starring role goes to our galaxy's Integrated Flux Nebula. (8-inch Officina Stellare Riccardi-Honders Veloce RH 200 astrograph at f/3, SBIG STL-11000M CCD camera, LRGB image with exposures of 120, 80, 80, and 80 minutes, respectively) • ***Harel Boren***

Send your images to:
Astronomy Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to readergallery@astronomy.com.

ESO

Star birth and death in the LMC

The Large Magellanic Cloud (LMC) is the Milky Way's biggest satellite galaxy, lying 160,000 light-years away. A new image from the Very Large Telescope at the Paranal Observatory in Chile shows a bright emission nebula called NGC 2035 (right) in the LMC, which is gravitationally condensing into new stars — a stellar nursery.

The nebula to the left of NGC 2035 is a bubble-shaped remnant from the death of a star in the LMC. This ancient supernova remnant resulted from the explosion of a massive star at the end of its life.

The image thus shows stellar recycling — the birth of new stars using gas from stars like the one lost as a supernova.


ONE HALF OF THIS IMAGE WAS TAKEN WITH A $2,499 ESPRIT
THE OTHER WAS TAKEN WITH A SCOPE THAT COST TWICE AS MUCH
Imager: Jerry Keith of Fort Worth, Texas (Three Rivers Foundation Volunteer)
Scopes: Sky-Watcher Esprit 100mm EDT f/5.5 World-class 4-inch astrograph
Mount: Takahashi EM200 Temma2M
Guiding: Orion SSAG Magnificent Mini AutoGuider
Camera: Canon 60Da @ 800 ISO
Exposure: 20 light frames and 20 dark frames @ 300 seconds. No flats, dark flats or bias frames were used. 30 light frames and 15 dark frames @ 30 seconds were used for toning down the core of M31. The same processing was used for both scopes.
Actually, the other telescope cost **more** than twice as much as the Esprit, but that's not really the point. The point is, do you see twice as much performance on one side of the page than the other? Take a close look. Are the stars twice as pinpoint? Is the color doubly corrected?
We don't think so.
If you don't think so either, perhaps you should consider purchasing a Sky-Watcher Esprit triplet. At Sky-Watcher USA we pride ourselves on offering products with world-class performance at affordable prices. Because we know there are other things you could be spending that money on. Like a mount. Or a camera. Or even a really, really sweet monster flat-screen television, just for fun.
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If you really want to spend twice as much for the same performance, we're not going to stop you. We will be **very** disappointed with you, though.
Sky-Watcher PROFESSIONAL

MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

June 2014: Saturn's grand show

As June begins, a trio of conspicuous planets stretches across the early evening sky from near the northwestern horizon to high in the east. **Jupiter** is the brightest of the three, and it appears low in the northwest as darkness falls on the 1st. Although you won't need any help to find it — at magnitude –1.9, it's the brightest point of light in the sky — a waxing crescent Moon nevertheless points the way from its perch less than 10° to the planet's upper left.

Jupiter lies among the background stars of eastern Gemini, south of the Twins' two brightest stars, Castor and Pollux. Even the smallest telescope reveals the planet's dynamic disk, which spans 33" across the equator, and its four brightest moons. But with Jupiter hanging relatively low in the sky, you'll have to wait for moments of good seeing to observe much detail in the planet's cloud tops. The giant world draws closer to the Sun as June progresses and will be visible only in twilight by month's end.

Although it is now two months past opposition and peak visibility, **Mars** remains a prominent object from dusk until well past midnight. It lies high in the northeast as twilight fades away. Shining at magnitude –0.5 early in the month, Mars dominates the background stars of Virgo. It appears some four times brighter than its host constellation's luminary, blue-white Spica, which lies some 15° to the Red Planet's right.

June should offer excellent views of Mars through a telescope. The planet appears 12" across at the beginning of the month, a value that shrinks to 10" by month's end. Mars' north pole currently tilts 25° in our direction, so the bright polar cap should stand out. The rest of the disk should feature several dusky surface markings at medium to high magnification. With Mars residing high in the evening sky and the planet's light passing through less of Earth's turbulent atmosphere, seeing conditions often will be good.

Saturn lies one constellation east of Mars among the relatively dim stars of Libra the Balance. Shining at magnitude 0.2, it appears some 10 times brighter than any of its stellar neighbors. As the heavens wheel overhead during the course of the night, the brighter stars of Scorpius follow close behind Saturn. It almost appears as if the Scorpion is attempting to capture the planet in its claws.

Saturn reached opposition last month and unquestionably ranks as the top planet for telescope owners in June. The ringed world appears superb nearly all night long, but it is at its best when it climbs highest in the north during late evening. Saturn's disk measures 18" across while the gorgeous rings span 41" and tilt 21° to our line of sight. A 10-centimeter or larger telescope easily reveals the dark Cassini Division in the rings and several of the planet's moons.

The Moon occults Saturn June 10 for residents in southern South Africa and the southwestern corner of Western Australia. From Cape Town, the planet disappears behind the dark limb of the waxing gibbous Moon at 17h16m UT and reappears at 18h16m UT.

Innermost **Mercury** also lurks in the evening sky, but you'll have to hunt for it in the twilight glow. On June 1, the planet lies some 8° above the northwestern horizon 30 minutes after sunset. Sweep the area well to the lower left of Jupiter with binoculars to pick up magnitude 1.2 Mercury. If you turn your telescope on the planet, you'll see a 10"-diameter disk with a pleasing crescent shape. Mercury disappears in the Sun's glare after June 10.

The remaining naked-eye planet rises nearly three hours before the Sun. **Venus** shines brilliantly at magnitude –3.9 and dominates the northeastern sky. It begins the month among the background stars of Aries, then crosses into Taurus during June's third week. It spends the last few days of the month forming a spectacular centerpiece as it passes between the Pleiades and Hyades star clusters. Through a telescope on the 15th, the planet spans 13" and shows a fat gibbous phase.

The starry sky

The distinct color contrast between ruddy Mars and Virgo's brightest star, blue-white Spica, spices up the evening sky this month. It also serves to draw attention to Spica itself, a fascinating object in its own right.

Spica gets its name from the fact that celestial cartographers historically depicted its host constellation, Virgo the Maiden, as holding an ear (or "spike") of wheat in her left hand. Similar names with the same meaning come from Turkey, Syria, and Persia. However, an Arabic name for the star translates into "unarmed," in the sense of being vulnerable to attack. It appears that this name arose because Spica is a relatively solitary bright star. Take a look around this part of the sky; from Scorpius in the east to the sinking Canis Major in the west, you'll see Spica ranks among the more isolated of the bright stars.

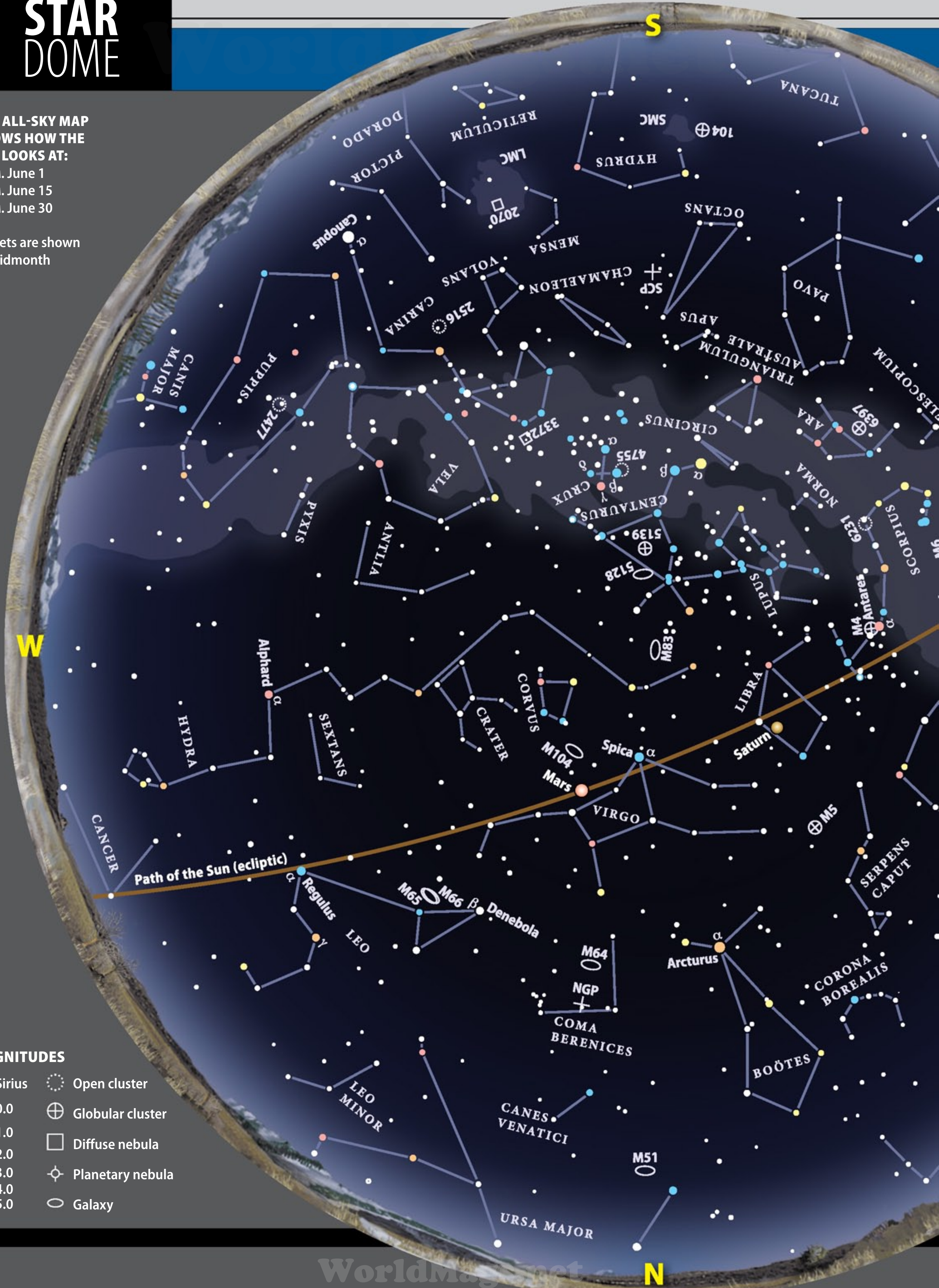
Spica appears to be a single star through any telescope. In 1890, however, German astronomer Hermann Carl Vogel discovered that it is a spectroscopic binary — a star that reveals its duplicity as the two stars orbit each other and their spectral lines periodically shift.

Spica's two stars lie extremely close — only 18 million kilometers separate their centers — which is why they appear single. Both are massive blue-white stars of spectral class B. The brighter one possesses approximately 10.5 times the Sun's mass while the other weighs in at 6 solar masses. The more massive star may explode as a supernova one day.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
9 P.M. June 1
8 P.M. June 15
7 P.M. June 30

Planets are shown at midmonth



MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

JUNE 2014

Calendar of events

1 Asteroid Vesta is stationary, 7h UT

The Moon passes 6° south of Jupiter, 8h UT

3 The Moon is at apogee (404,954 kilometers from Earth), 4h25m UT

5 First Quarter Moon occurs at 20h39m UT

7 Mercury is stationary, 10h UT

Asteroid Ceres is stationary, 22h UT

8 The Moon passes 1.6° south of Mars, 1h UT

10 Neptune is stationary, 6h UT

The Moon passes 0.6° south of Saturn, 19h UT

13 Full Moon occurs at 4h11m UT

15 The Moon is at perigee (362,065 kilometers from Earth), 3h29m UT

18 The Moon passes 5° north of Neptune, 10h UT

19 Last Quarter Moon occurs at 18h39m UT

Mercury is in inferior conjunction, 23h UT

21 The Moon passes 1.6° north of Uranus, 3h UT

June solstice occurs at 10h51m UT

Jupiter passes 6° south of Pollux, 12h UT

24 Asteroid Amphitrite is at opposition, 9h UT

The Moon passes 1.3° south of Venus, 13h UT

27 New Moon occurs at 8h08m UT

The Moon passes 5° south of Jupiter, 3h UT

30 The Moon is at apogee (405,930 kilometers from Earth), 19h10m UT